6 Degree of Freedom Splash
Pattern Generation Tool

Release: 1.1.0

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Forward

While the general layout and presentation of knowledge in this text is such that the user may read it "cover to cover," the author doubts that many users endeavor to do so. Rather, it is expected that this text will primarily be used as reference. As a result of this assumption the style of this text is rather stilted; it is often short and sweet to a nearly excessive degree. The text also repeats itself in several places as it was judged that redundancy of information was preferable to forcing the user to flip through several sections of the User's Manual just to perform or understand one facet of the simulation's operation or use.

That said, this is also a convenient time and place for me to acknowledge those who have influenced me in ways that either made this work happen or made my job easier. I would like to thank the following individuals for their encouragement, knowledge, help, and/or inspiration as appropriate:

Mr. Ed Brown
Mr. Ray Calkins
Mr. David McCue
Mr. Tom Rouse
Dr. Ned Smith
Mr. Rick Wills

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Introduction

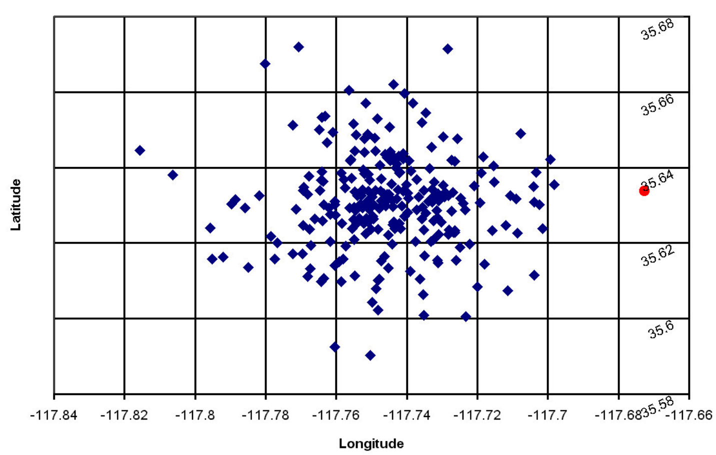
What Splash is

Splash is a wind-weighted 6 degree-of-freedom (6DOF) rocket simulation with statistics-based impact analysis capability. Splash is intended not just for the nominal trajectory analysis that most simulations are, but also for splash pattern generation consistent FAA/OST requirements. This means that Splash can provide the data used to determine not just a nominal impact point but an impact zone complete with statistics to back up the likelihood of a vehicle impact in any given region. No other simulation package available at a reasonable price[1] offers this capability.

Splash provides more capability and tracks more variables than other consumer-level simulation packages (and thus, provide data that comes closer to matching reality) available today. Splash's features include:

- Wind effects (weather cocking).
- Earth modeled as a rotating oblate spheroid.
- Gravitational effects that vary with altitude *and* latitude.
- An altitude model that extends to 632 km above sea level (ASL).
- Clustering of up to 5 motors per vehicle stage.
- Uncertainty analysis for 18 different vehicle/scenario parameters.

To better illustrate what all this means, imagine your typical rocket simulation. The simulation will say that the rocket goes up and comes down in a certain location. Question: What are the odds that the actual rocket would impact the exact location specified? Answer: About zero. So how close to the simulation specified location can you expect your rocket to land? Most simulations will provide no insight as to the answer of that second question. Splash provides a realistic idea of where the rocket *might* land.



A splash pattern representing 250 possible impact points.
The launch point is designated by the red circle on the right.

The figure above is a plot listing 250 potential impact points of a particular rocket. The distribution of the impact points illustrates not just a nominal impact point, but provides a level of confidence with respect to the likelihood of an impact in any given region. Such data is indispensable in pre-launch safety analysis and is also of use in determining possible locations for wayward rockets. It is this capability that sets Splash apart.

[1] The author is prepared to retract this statement the moment he is made aware of another simulation package of similar capability and price is made known to it.

What Splash *isn't*

First and foremost, Splash is *not* a modeling package. In the eyes of the general public, there is no perceived no difference between modeling and simulation. There is, however, a difference. Modeling involves the determination of static performance parameters. For rockets, this means things such as drag coefficients, mass properties, etc. In contrast, simulation involves putting models in motion in the context of set timelines and scenarios. In lay terms, models may be thought of as the input for simulations[2].

Beware: Splash does not determine drag coefficients, mass properties, thrust curves, or any other performance parameter. These parameters are instead required as input from the user. The user may obtain such data from other programs[3], hand calculations, actual test data, a Ouija board, or any other means the user deems up to the task. Splash "merely" integrates the performance data and puts it in motion.

Thus, the user will be required to independently provide the following data for each stage (in no particular order):

- Gross vehicle geometric properties
    - Length
    - Nominal diameter (and thus, frontal area)
- Mass properties
    - Mass
    - Center of gravity as a function of mass
    - Moments of inertia at launch
    - Products of inertia at launch
- Aerodynamic properties
    - Ca as a function of Mach and AOA
    - Cb as a function of Mach and angle of attack (AOA)
    - Cn as a function of Mach and AOA
    - CP as a function of Mach and AOA
- Fin information
    - Location, number and dimensions
- Propulsion system
    - Thrust/time curve
    - Propellant mass
    - Sea level total impulse
    - Nozzle exit area
- Recovery system
    - Conditions of deployment
    - Diameter
    - Sub-sonic drag coefficient
- Current launch site conditions
    - Longitude, latitude, and altitude
    - Barometric pressure and temperature
    - Wind speed and direction as a function of altitude

[2] This is not entirely true, but it is close enough for the purposes of this discussion.

[3] Examples of such programs include but are not limited to: ADAM, AeroCFD, AP98, DATCOM, HyperCFD, PEP, RockSim, and Zeus.

Models

Earth

The Earth model employed by Splash is based on the WGS-84[4] Earth model. Splash models the Earth as perfectly smooth, rotating spheroid of uniform density. The primary parameters of this model are as follows:

Major Axis (m)	6378137.0
Minor Axis (m)	6356752.3
Average Radius (m)	6371008.7
Angular Velocity (rad/s)	72.92115e-6
Mass (kg)	5.979e24
Mass * Gravitational constant (m^3/s^2)	3.986004418e14
"Standard" Gravitational Acceleration (m/s^2)	9.80665

Note that from the perspective of a fixed, Earth-centered coordinate system, gravitational acceleration is assumed to be strictly a function of distance to the center of the Earth. But this is only part of the story. The fact that the Earth is non-spherical coupled with its rotation yields a more complex gravitational model when by an observer on the Earth's surface. The result is that gravitational acceleration as seen by an observer on the Earth's surface varies not only with altitude (as one would expect) but also with latitude (as one may not expect).

Atmosphere

Two different atmospheric models are used by Splash. The first model, used for density altitude correction initialization defines atmospheric conditions as the inverse of a 5th order polynomial. The other model produces data that matches the ISO 1978 standard atmosphere to an altitude of 631 km above sea level and is used by Splash at all times during flight modeling.

Vehicle

The vehicle(s) modeled by Splash are assumed to be perfectly rigid, axisymmetric bodies of up to 3 stages. The specific aspects of the vehicle model have been broken down into more logical, more manageable pieces: mass properties, aerodynamics, and propulsion.

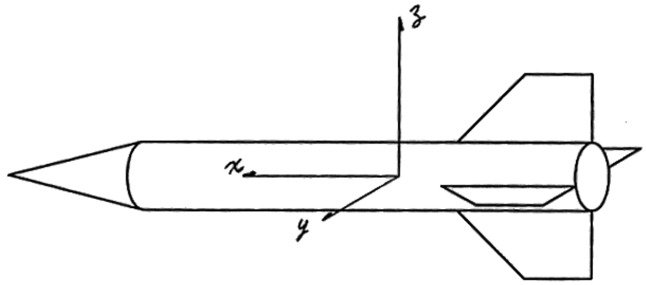
Mass Properties

The mass properties tracked by Splash are as follows: length, nominal diameter, mass, center of gravity, and the moments and products of inertia. Length, diameter, and mass are obviously straightforward in nature; the center of gravity as well as the moments and products of inertia do warrant additional discussion, however.

The center of gravity is assumed to lie on the vehicle's axis of symmetry. It does, however, move fore and aft as a function of mass as defined by the user.

[4]. For those not familiar with the WGS-84 model, it is the primary Earth model employed by the Global Positioning Satellite (GPS) system. For more information, see "Department of Defense World Geodetic System 1984", National Imagery and Mapping Agency (NIMA) document number NIMA TR8350.2. This document is available to the public for download at http://www.nima.mil.

The vehicle's local coordinate system is centered about the current center of mass and orientated similar to industry standard (X = forward, Y = port, Z = up).

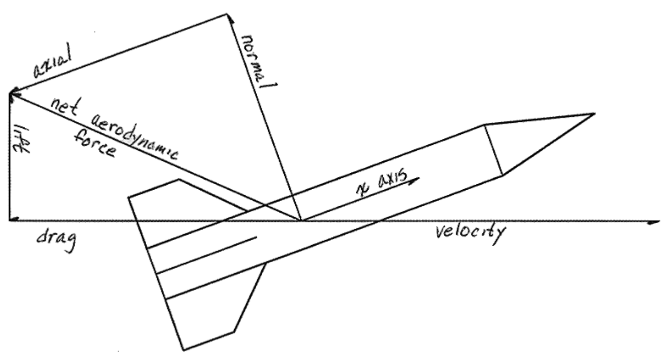


A sketch illustrating the local vehicle coordinate system.

Aerodynamics

Given Splash's assumption of an axisymmetric vehicle, it logically follows that the aerodynamic assumptions used by Splash are axisymmetric as well. This means that current roll angle does not affect axial or normal forces at non-zero angles of attack.

One aspect of Splash's aerodynamic model that may throw many users off balance is the use of axial and normal aerodynamic forces rather than the lift and drag forces most people are familiar with. Lift and drag forces are respectively defined to be perpendicular and opposite to the velocity vector. By contrast, normal and axial forces are defined as perpendicular and opposite to the vehicle's own longitudinal axis. Both systems are valid. Both systems provide for vector addition that yields the net aerodynamic forces acting upon the vehicle. But to understand why the axial/normal force pairing is advantageous for rocketry work one need only remember that the vast majority of hobby rocketry accelerometers are one-dimensional; they record accelerations in-line with the vehicle longitudinal axis. As a result the data processing required to properly interpret data from such instrumentation is reduced.



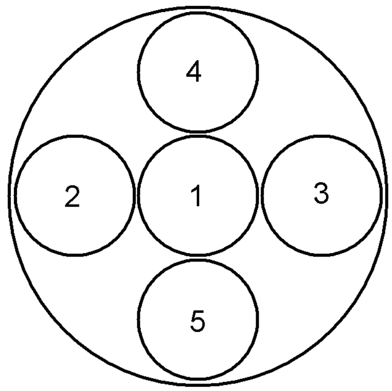
A sketch illustrating the relationships between lift, drag, normal and axial forces and their orientations with respect to the vehicle's longitudinal axis and velocity vector.

Splash models the axial force, normal force, and center of pressure as a family of second order polynomials that are functions of angle of attack and Mach number.

Propulsion

Each stage modeled by Splash is assumed to possess a cluster of up to 5 motors. The engines are arranged in a cluster as seen in the picture below. Obviously, not every stage has 5 motors; most, in fact

will not. For stages with fewer than 5 motors, the motors that do not exist in reality are simply simulated as motors that produce zero thrust and consume zero fuel.



The methodology used to describe any single motor is based upon proven methodologies used in government laboratories to model rocket motors within the context of kinematic analysis codes. While these methodologies assume constant specific impulse throughout the motor's burn, they do provide thrust corrections associated with the local ambient atmospheric pressure. The input requirements for these methodologies is as follows:

- Total impulse at sea level (N*s).
- Propellant mass (kg)
- Nozzle exit area (m^2)
- Time/Thrust curve (s, N)

Installation

Assuming a system capable of running Splash[5], installation of Splash is trivial. The distribution disk is set up to automatically launch the installation routine upon insertion into the disk drive. If for any reason the installation routine should fail to automatically start up, the user may manually start the routine. The installation routine is found in the distribution disk' s root directory and is called "installer.exe." Installer handles everything associated with Splash installation with minimal input required of the user.

At installation, the user is asked to provide the name of a directory in which Splash will be installed. The default directory is "C:\Program Files\Splash" but the user may dictate any directory that suites his or her fancy by manipulating the pull-down menus and text box (at the upper right) provided.

The directory dialog within the install routine.

Upon completion of the install, Splash is fully functional. Further, Splash makes no modifications to the system registry and all files required at runtime are found within the Splash directory or subdirectories thereof. As a result, uninstalling Splash is as simple as deleting the Splash directory.

[5] System requirements: Win95+, Pentium, CD-ROM, 10 MB free hard drive space.

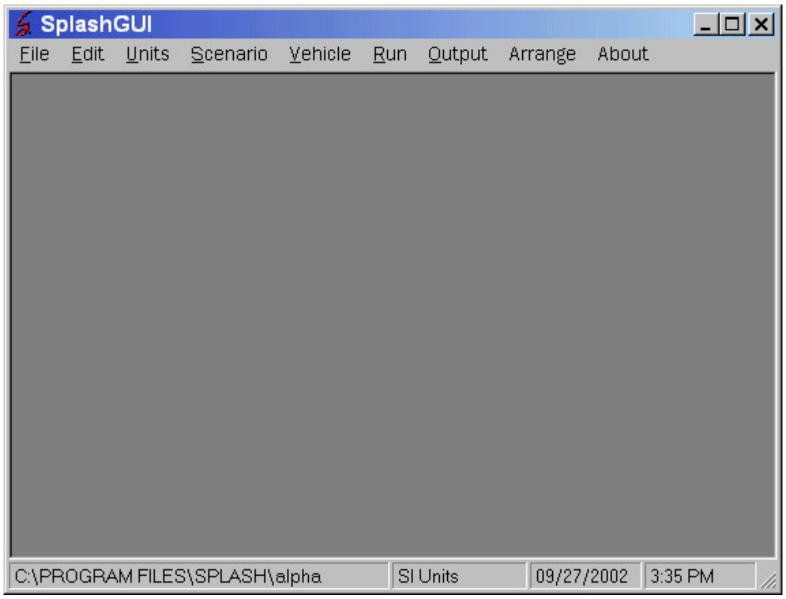
The GUI Application

Main Window

In addition to providing the pull-down menus that drive all user-input in Splash, the main window also provides some feedback to the user in the status bar at the bottom of the window. Of primary interest are the base file name and unit system panes.

The base file name pane provides the current path and file name in which the data contained within the memory of the Splash GUI will be saved in the event the user commands Splash to save its data.

Similarly, the unit system pane informs the user of the current unit system - SI or English - for which input/output is expected/presented. The user may change the unit system at will by selecting the desired unit system from the pull-down menu at the top of the main window. Note, however, that before the unit system may be changed, all input/output windows must be closed.



The main window.

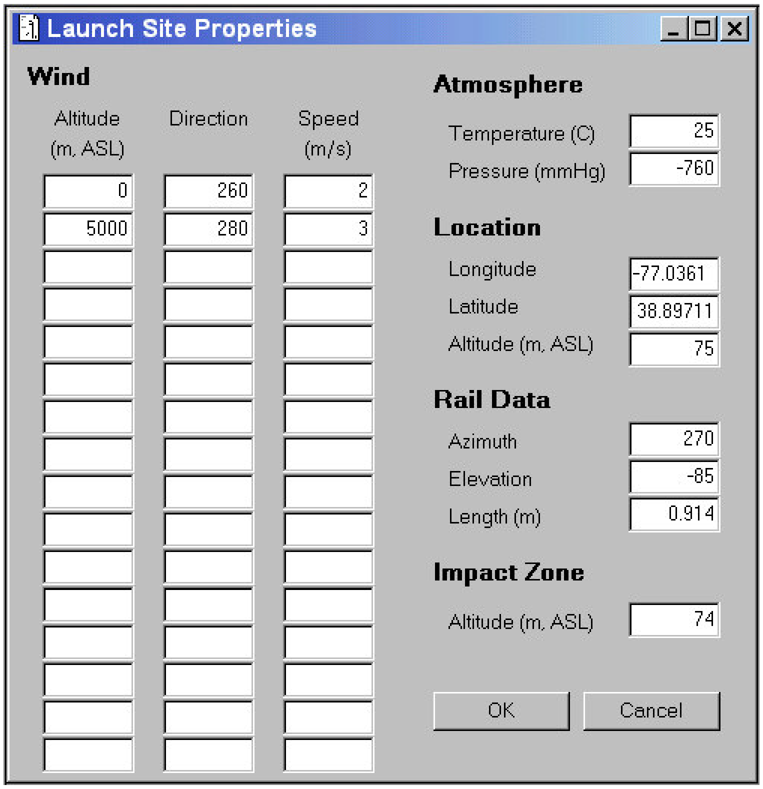
Input Windows

A 6DOF simulation obviously requires a lot of data describing any number of conditions and properties applicable not only to the vehicle, but to the launch environment as a whole. Splash attempts to break up this mass of data into smaller, logically organized blocks of data. A window dedicated to each block of data handles the input of the appropriate data. As a result it is believed that data input is as straightforward and intuitive as possible. In other words, the GUI should be largely self-explanatory to any experienced rocketeer.

Launch Site

As the name of this input window would imply, the Launch Site input window contains all data concerned with the launch site. This includes everything from the position and orientation of the launch rail to the altitude (ASL) of the anticipated impact zone.

The launch site window is accessed through the 'Scenario" pull-down menu found at the top of the main Splash window. Once opened, the Launch Site window will appear similar to the window shown below.



The Launch Site input window.

The contents of each input box in the launch site window is as follows:

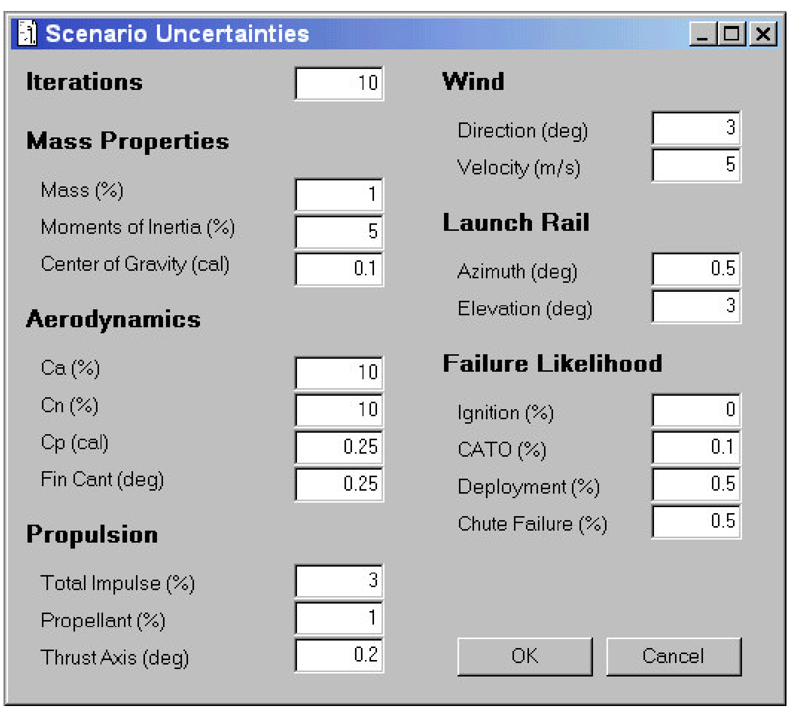
Classification	Column/Box	Description
Wind	Altitude	The altitude (m or ft, ASL) for which the wind data (direction and speed) in the next columns is valid.
	Direction	The direction (degrees) from which the wind is *originating*. An angle of zero degrees defines a wind from the North; an angle of 90 degrees defines a wind from the East, etceteras.
	Speed	The speed (m/s or ft/s) at which the wind is blowing.
Atmosphere	Temperature	The ambient temperature (deg C or F) at the launch site. This data is used to determine the local air density and thus the correct density altitude. It is not, however, used to modify local sonic conditions.
	Pressure	The barometric pressure (mmHg or inHg) at the launch site. This data is used to determine the local air density and thus the correct density altitude. If the current barometric pressure is unknown or if the user simply wishes to use a standard atmosphere, a negative value in this block will turn off atmospheric corrections.
Location	Longitude	The longitude (in the WGS-84 coordinate system) of rocket's center of gravity at the start of the simulation. East longitude is defined as a positive angle while West longitude is defined as a negative angle.
	Latitude	The latitude (in the WGS-84 coordinate system) of rocket's center of gravity at the start of the simulation. North latitude is defined as a positive angle while South latitude is defined as a negative angle.

	Altitude	The altitude (m or ft, ASL in the WGS-84 coordinate system) of the rocket's center of gravity at the start of the simulation.
Rail Data	Azimuth	The azimuth angle (degrees) in which the launch rail (and rocket) is pointing at the start of the simulation. An angle of zero degrees defines a rail pointing to the North; an angle of 90 degrees defines a rail pointing to the East, etceteras.
	Elevation	The elevation angle (degrees) in which the launch rail (and rocket) is pointing at the start of the simulation. An angle of -90 degrees defines a rail pointing straight up; an angle of 0 degrees defines a horizontal launch rail.
	Length	The distance (m or ft) the vehicle must travel before it is released from the launch rail.
Impact Zone	Altitude	The altitude (m or ft, ASL) of the impact zone' s terrain Most of the time this will be the same as the launch rail altitude, but not always. An obvious exception to this rule would be an air-launched system.

Uncertainties

The primary purpose of Splash is to generate splash patterns for sounding rockets. Obviously, one must possess a working knowledge of the uncertainties associated with any given vehicle and launch scenario. The Uncertainties input window defines these uncertainties.

The Uncertainties window is accessed through the 'Scenario" pull-down menu found at the top of the main Splash window. Once opened, the Uncertainties window will appear similar to the window shown below.



The Uncertainties input window.

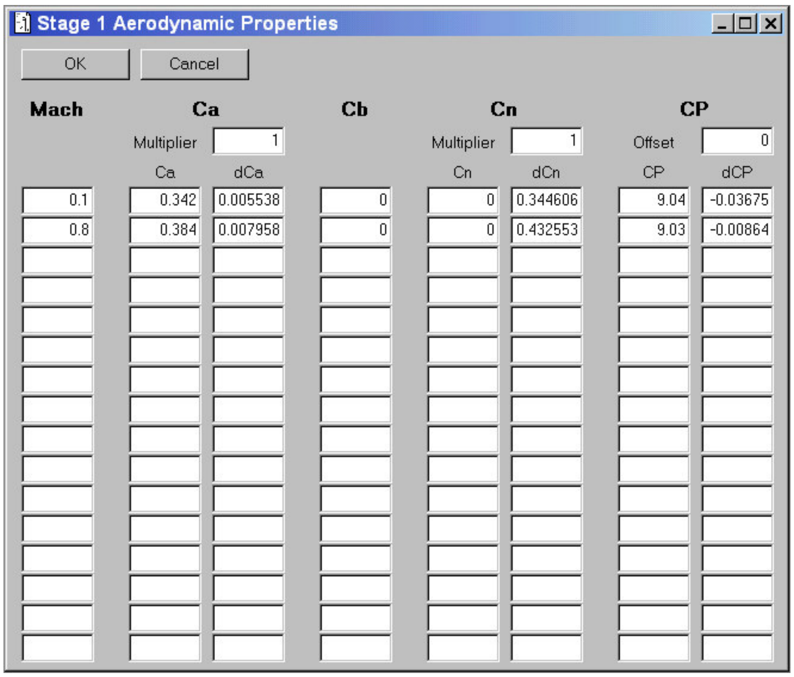
The contents of each input box in the uncertainties window is as follows:

Classification	Column/Box	Description
Iterations		The number of iterations one desires to run for the given scenario. It is recommended that the user start with a small number (5-10) to see if the simulation has any obvious problems before committing oneself to a splash pattern generation (a task that can take many hours to complete). The number of iterations required for splash pattern generation will vary depending upon the complexities of the mission and the needs of the user. Realistic iteration values range anywhere from 100 to 30,000.
Mass Properties	Mass	The single standard deviation uncertainty in launch mass expressed as a percentage.
	Moments of Inertia	The single standard deviation uncertainty in moments and products of inertia expressed as a percentage.
	Center of Gravity	The single standard deviation uncertainty in center of gravity in calibers.
Aerodynamics	Ca	The single standard deviation uncertainty in axial force coefficient expressed as a percentage.
	Cn	The single standard deviation uncertainty in normal force coefficient expressed as a percentage.
	CP	The single standard deviation uncertainty in center of pressure in calibers.
	Fin Cant	The single standard deviation uncertainty in fin cant angle in degrees.
Propulsion	Total Impulse	The single standard deviation uncertainty in total impulse expressed as a percentage.
	Propellant	The single standard deviation uncertainty in propellant mass expressed as a percentage.
	Thrust Axis	The single standard deviation uncertainty in thrust alignment in degrees.
Wind	Direction	The single standard deviation uncertainty in wind origin direction in degrees.
	Velocity	The single standard deviation uncertainty in wind speed in meters or feet per second.
Launch Rail	Azimuth	The single standard deviation uncertainty in launch rail azimuth angle in degrees.
	Elevation	The single standard deviation uncertainty in launch rail elevation angle in degrees.
Failure	Ignition	The likelihood of single motor ignition failure expressed as a percentage.
	CATO	The likelihood of single motor catastrophic failure expressed as a percentage. Note that all CATOs are assumed to occur at motor ignition.
	Deployment	The likelihood of recovery system deployment failure expressed as a percentage.
	Chute Failure	The likelihood of recovery system failure expressed as a percentage.

Aerodynamics

As the name of this input window may imply, the Aerodynamics input window contains data concerned with gross vehicle aerodynamics.

The Aerodynamics window is accessed through any of the "Vehicle->Stage" pull-down menus found at the top of the main Splash window. Once opened, a Aerodynamics window will appear similar to the window shown below.



The Aerodynamics input window.

The contents of each input box in the aerodynamics window is as follows:

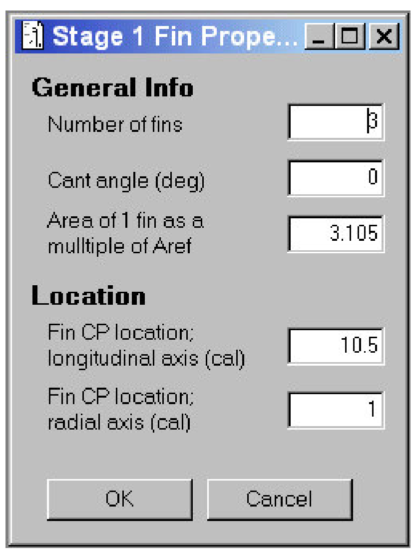
Classification	Column/Box	Description
Mach		
Ca	Multiplier	The axial force multiplier. This is simply a constant by which the nominal axial force coefficient is multiplied by to facilitate drag sensitivity studies. Normally, the associated value will be 1.0, but suppose the user wishes to model a 10% drag increase. In which case, the user would merely have to use an axial force multiplier of 1.1 rather than re-calculate and re-type the entire axial force coefficient table.
	Ca	The zero angle of attack axial force coefficient.
	dCa	The derivative of the axial force coefficient with respect to angle of attack.
Cb		The base drag coefficient. The user should ensure that the base drag coefficient is used; many aeroprediction codes list the base pressure coefficient. The two coefficients are related, but not equivalent.

Cn	Multiplier	The normal force multiplier. This is simply a constant by which the nominal normal force coefficient is multiplied by to facilitate normal force sensitivity studies. Normally, the associated value will be 1.0, but suppose the user wishes to model a 10% lift increase. In which case, the user would merely have to use a normal force multiplier of 1.1 rather than re-calculate and re-type the entire normal force coefficient table.
	Cn	The zero angle of attack normal force coefficient (usually zero).
	dCn	The derivative of the normal force coefficient with respect to angle of attack.
CP	Offset	The center of pressure offset. The offset is simply a constant that is added to the nominal CP to facilitate stability sensitivity studies. Normally, the associated value will be 0.0, but suppose the user wishes to model a CP shifted one caliber forward. In this case, the user would use a CP offset of -1.0 rather than re-calculate and re-type the entire center of pressure table.
	CP	The zero angle of attack center of pressure (in calibers).
	dCP	The derivative of the center of pressure with respect to angle of attack.

Fins

As the name of this input window implies, the Fins input window contains data concerned with fins. It should be prominently noted that Splash only uses fin data for yaw/pitch/roll damping. Fin data does not affect lift, drag, or stability in the normal sense; the effects of fins on these vehicle attributes are expected to have been included in the gross vehicle aerodynamics.

The Fins window is accessed through any of the "Vehicle->Stage" pull-down menus found at the top of the main Splash window. Once opened, a Fins window will appear similar to the window shown below.



The Fin input window.

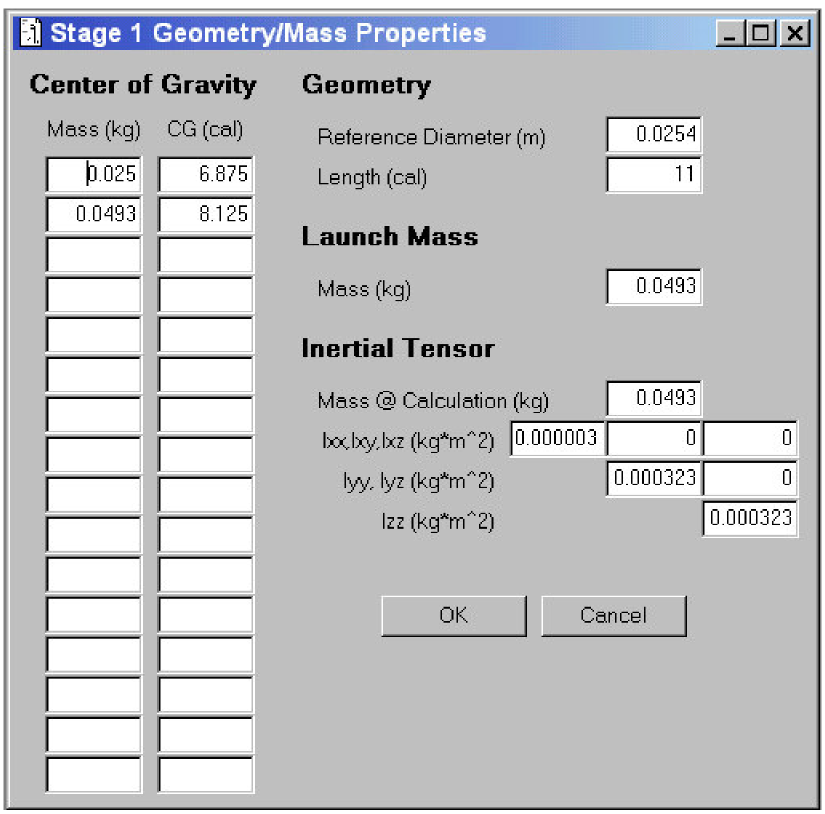
The contents of each input box in the fin properties window is as follows:

Classification	Column/Box	Description
General Info	Number of fins	The number of fins possessed by the rocket. Valid numbers range from 3 to 6.
	Cant angle	The fin cant angle in degrees.
	Area of 1 fin	The area of one side of one fin expressed as a multiple of the aerodynamic reference area for the overall vehicle.
Location	Fin CP, longitudinal	The longitudinal center of pressure of a fin, measured in calibers from the tip of the vehicle' s nose. A good rule of thumb for this value is the ¼ chord mark on the fin.
	Fin CP, radial	The radial center of pressure of a fin, measured in calibers from the centerline of the vehicle. A good rule of thumb for this value is ½ caliber added

Geometry/Mass

Obviously, the geometry and mass properties window defines the gross vehicle dimensions as well as mass properties. It should be noted that the nominal diameter entered on this page defines the reference area used for all aerodynamic calculations; i.e. Aref = PI/4 * Diam^2.

The geometry and mass properties window is accessed through any of the "Vehicle->Stage" pull-down menus found at the top of the main Splash window. Once opened, a geometry/mass properties window will appear similar to the window shown below.



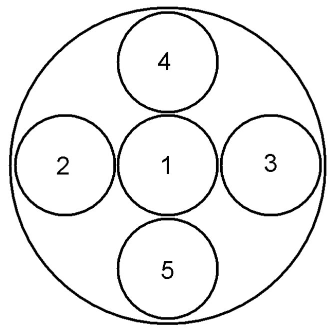
The geometry/mass properties input window.

The contents of each input box in the geometry/mass properties window is as follows:

Classification	Column/Box	Description
Center of Gravity	Mass	The mass (kg or lbm) associated with the CG listed in the next column. At least two masses should be listed and all should be ascending order.
	CG	The center of gravity (calibers) that corresponds to the mass listed in the previous column.
Geometry	Diameter	The nominal diameter of the vehicle (m or ft). This parameter defines "1 caliber" as well as the reference area used for most aerodynamic constants (Aref = PI*Diameter^2/4).
	Length	The nominal length of the vehicle (calibers).
Launch Mass		The initial mass (kg or lbm) of the stage or vehicle in question.
Inertial Tensor	Mass	The mass (kg or lbm) corresponding to the moments and products of inertia that make up the inertial tensor. Obviously, moments/products of inertia vary with mass. Splash assumes a linear relationship between the mass and moments/products of inertia. This is not always the best assumption, but it is reasonable and simplifies user input requirements.
	Ixx	The moment of inertia (kg*m^2 or lbm*ft^2) taken about the X axis (longitudinal/"forward").
	Ixy	The product of inertia (kg*m^2 or lbm*ft^2) taken in the XY plane.
	Ixz	The product of inertia (kg*m^2 or lbm*ft^2) taken in the XZ plane.
	Iyy	The moment of inertia (kg*m^2 or lbm*ft^2) taken about the Y axis ("port").
	Iyz	The product of inertia (kg*m^2 or lbm*ft^2) taken about the YZ plane.
	Izz	The moment of inertia (kg*m^2 or lbm*ft^2) taken about the Z axis ("up").

Propulsion

While providing perhaps the most obviously needed data in a rocket simulation, the propulsion system input window is visually the most intimidating. It really is quite simple though. Splash models each stage as if it possessed five motors arranged as seen in the sketch below. Obviously, not every vehicle in the real world has five rocket motors in it - most have considerably fewer. To allow for this fact, Splash does not require that every motor provide thrust, have a nozzle, or even have any mass for that matter. In other words, motors that are not found in the real-world vehicle Splash is modeling are mathematically nullified, thus ensuring that they do not affect simulation results.



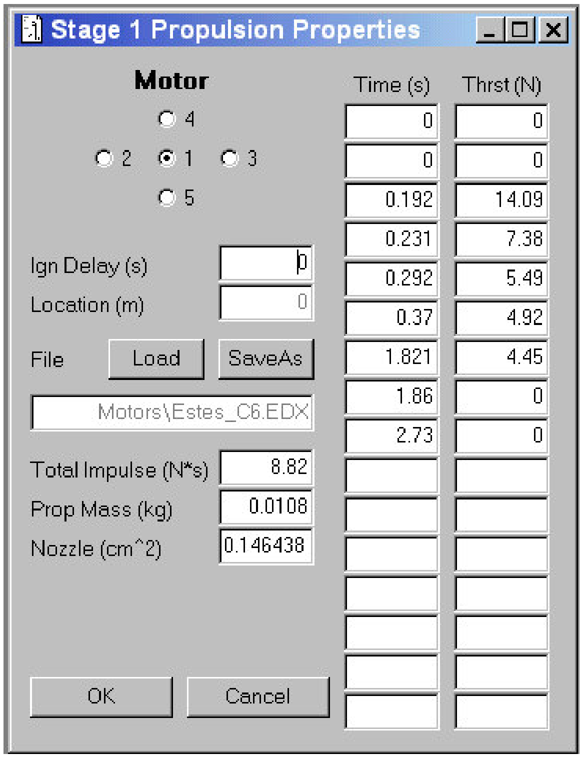
The configuration of all five motors in each stage.

All these null motors may make the user wonder why include provisions for so many motors given the fact that the vast majority of the vehicle stages out there possess only one or two motors. The answer is versatility. By varying which motors are nullified the user may effectively model balanced clusters of 1, 2, 3, 4, or 5 motors. The table below illustrates in detail how various clusters may be modeled.

Motors in Cluster	**Active Motors**	**Null Motors**
0	-	1,2,3,4,5
1	1	2,3,4,5
2	2,3	1,4,5
3	1,2,3	4,5
4	2,3,4,5	1
5	1,2,3,4,5	-

The propulsion window allows the user to select any of 167 different pre-defined (commercial) motors ranging from C impulse to N. However, by selecting a "custom" motor the user is also allowed to define his/her own motors. Custom motors have no size, thrust, or burn length limitations.

The propulsion window is accessed through any of the "Vehicle->Stage" pull-down menus found at the top of the main Splash window. Once opened, a propulsion system window will appear similar to the window shown below.



The propulsion system input window displaying data for motor #1.

The contents of each input box in the propulsion system window is as follows:

Classification	Column/Box	Description
Motor X (1-5)	Ign Delay	The delay (seconds) from the activation of the current stage until the ignition of the motor in question. In most cases, the ignition delay will be zero. Non-zero numbers are, however, desired in the event of air-started motors or multiple stage rockets with coast periods between stage separations and ignitions.
	Location	The motor's off-centerline distance (m or ft) in accordance with the motor configuration sketch seen previously in this section of the manual[6]. Being on the centerline by definition, motor 1 will always have an off-centerline distance of 0.0. The rest of the motors should obviously have non-zero offset distances.
	File	The file that contains pre-programmed motor data for the motor in question. Performance data for custom motors is loaded or saved as appropriate to or from the listed file when the load/save buttons are clicked.
	Total Impulse	The *sea-level* total impulse (N*s or lbf*s) of the motor in question.
	Prop Mass	The mass of propellant (kg or lbm) contained within the motor in question.
	Nozzle	The total exit area of all nozzles (cm^2 or in^2) possessed by the motor in question.

[6] Note that the number 1 motor is assumed to be on the vehicle's center line and thus the off-centerline distance is always zero.

	Time	The data that defines the time axis on the thrust/time curve. Time is measured in seconds.
	Thrust	The data that defines the thrust axis on the thrust/time curve. Units are unimportant as the curve will ultimately be scaled to match the previously defined total impulse.

Staging/Recovery

The manner in which Splash handles staging and recovery system deployment is probably the most unique piece of programming logic within Splash. Rather than simply staging/deploying by time, altitude, or body elevation as many systems do, Splash allows the user to construct more complex staging/deployment criterion by combining up to three logical tests that are evaluated in series[7].

Each test performed for staging/deployment contains three pieces of information. The first piece of information is the flight parameter for which the testing is dependent. Examples of the flight parameter are altitude, time, and dynamic pressure. The second piece of information is a numerical value to which the flight parameter is compared. The final piece of information is simply a flag to indicate whether the flight parameter is expected to be greater than or less than the numerical value indicated.

The flight parameters for which staging/deployment may be linked to are as follows:

Parameter[8]	**Description**
Altitude	Altitude above sea level (m or ft).
delta Altitude	Change in altitude above sea level (m or ft).
Atmospheric Pressure	Local atmospheric pressure (Pa or psi).
delta Atmospheric Pressure	Change in local atmospheric pressure (Pa or psi).
Body Elevation Angle (theta)	Vehicle body angle with respect to horizontal[9] (deg).
delta Body Elevation Angle (dtheta)	Change in vehicle body angle with respect to horizontal (deg).
Dynamic Pressure	Dynamic pressure at leading edge (Pa or psi).
delta Dynamic Pressure	Change in dynamic pressure at leading edge (Pa or psi).
Flight Angle (gamma)	Velocity vector angle with respect to horizontal[10] (deg).
delta Flight Angle (dgamma)	Change in velocity vector angle with respect to horizontal (deg).
Immediate	Immediately evaluate test as true (do not use the test in question).
Mach Number	Vehicle Mach number.
delta Mach Number	Change in vehicle Mach number.
Never	Never evaluate test as true (never stage/deploy).
Time	Current elapsed time since launch (s).
delta Time	Change in elapsed time (s).

[7] Three bone fide tests are rarely required in the world of hobby rocketry; two tests is usually enough to handle even the largest project. Still, the third test is provided to cater to the "1%ers" out there.
[8] The value of the parameter in question at the start of the current test is used as the baseline for all "delta" parameters. I.E., a "delta Time" of 0.1 commands the simulation to "Wait 0.1 second, regardless of how much time has elapsed since the simulation started."
[9] Sometimes referred to as 'theta."
[10] Usually referred to as "gamma."

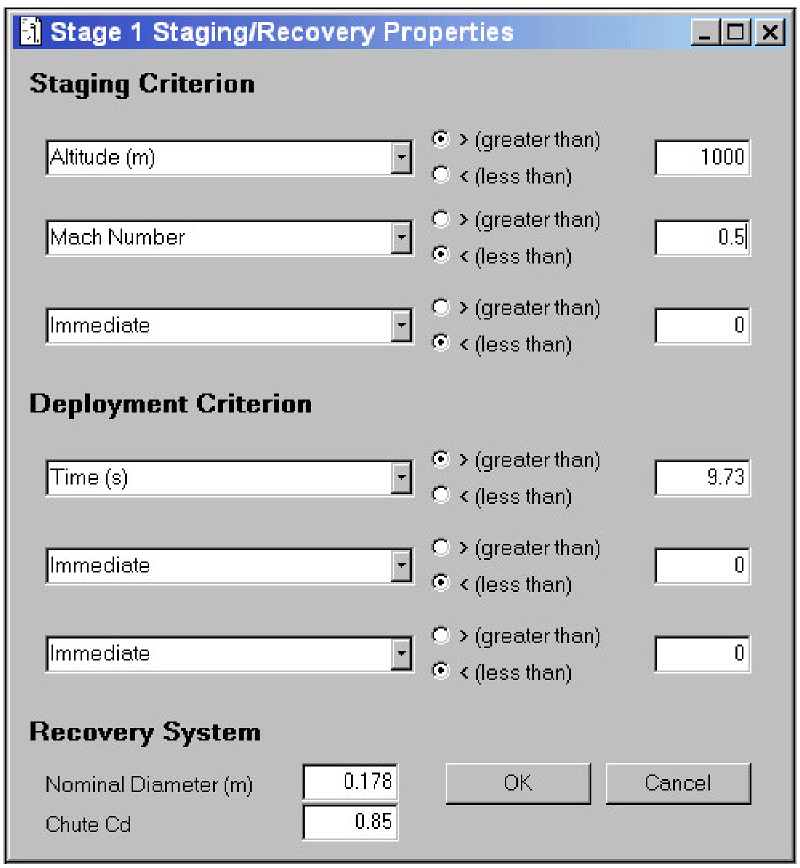
While this may sound confusing at first, it is actually very simple. For example, the staging criterion shown in the screen capture below indicates the following behavior:

1. Wait until altitude is greater than 1000 m.
2. Then wait for Mach number to drop below 0.5.
3. Then immediately stage (3rd test unused).

The staging/recovery window is accessed through any of the 'Stage" pull-down menus found at the top of the main Splash window.

The only remaining input requirements found in the staging/recovery system input window are the nominal diameter and chute Cd input blocks. Splash assumes a recovery system that consists of a single circular parachute. This parachute's nominal diameter and drag coefficient are thus, obviously defined by the two remaining data input boxes.

Box	**Description**
Nominal Diameter	Parachute nominal diameter (m or ft).
Chute Cd	Parachute drag coefficient (assuming reference area equal to frontal area of parachute).



The staging/recovery input window.

Running the Simulation

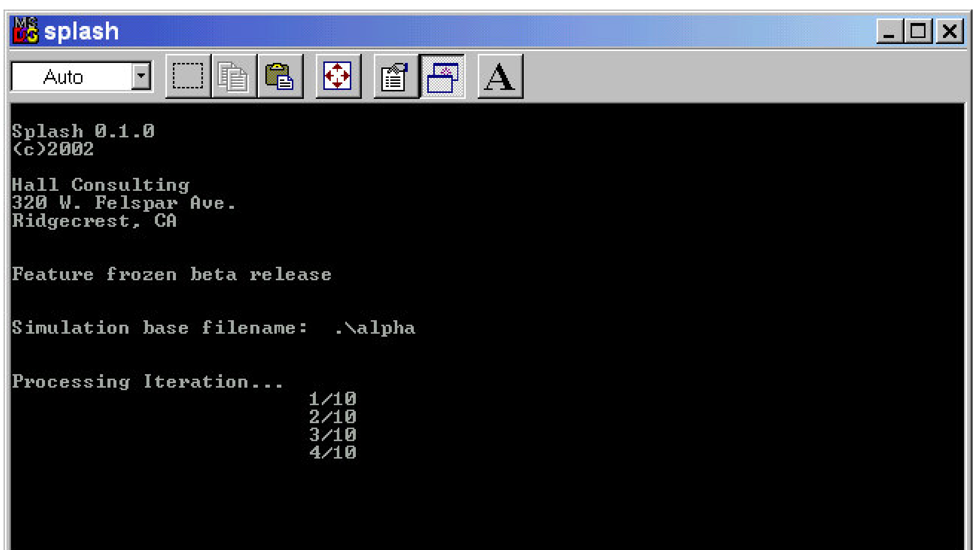
Once the user is satisfied that he/she has set up the simulation scenario(s) to his satisfaction, it is obviously time to run the simulation. To do so, the user at this time selects "Run" from the pull-down menus at the top of the main Splash window.

When "Run" is selected, Splash will immediately perform three tasks. Saving all input data to disk is the first task[11]. Once saving is completed, Splash will perform a simple "sanity check" on the input data to ensure there are no obvious blunders in the data (Example: a second stage mass higher than the first stage burn out mass). Finally, Splash will invoke the number cruncher that is the heart and soul of Splash - the Splash console application.

When the console application is called, a new window will appear on the screen. This window is the console application and is an entity unto itself. It neither knows nor cares about the existence of the Splash GUI. Similarly, the Splash GUI has no way of knowing what sort of progress the console application has made. The upside of this behavior is that the GUI isn't completely locked up while it awaits for simulation results from the number cruncher. The downside of this behavior is the user must use a small bit of self control and adhere to the following:

1. Do not attempt to run the console application again until the console application has closed itself.
2. Do not attempt to access trajectory files (either from a DOS window or through the GUI) until the console application indicates that it has started on its second iteration.
3. Do not attempt to access the splash pattern file (either from a DOS window or through the GUI) until the console application has closed itself.

The GUI *should* prevent the user from doing any of the above, nonetheless the user is to consider himself warned lest he find a way to circumvent the GUI's efforts at preventing the user from doing something stupid.



The console application as it starts the 4th iteration out of 10 requested.

[11] The data is saved exactly as if the user had selected "Save" from the "File" pull-down menu. This step is required due to the program architecture employed by Splash.

Output

The Splash console application generates anywhere from four to six data streams depending upon the number of stages to be modeled in the simulation. These streams provide user feedback, trajectory data, and splash pattern data.

The most obvious of these streams is the text sent to the console application's window. The console application output (seen above) provides no data concerning scenario specifics but it does provide the user with information regarding overall simulation progress. In other words, it displays a counter showing how many iterations were requested and which iteration is currently being processed - nothing less, nothing more.

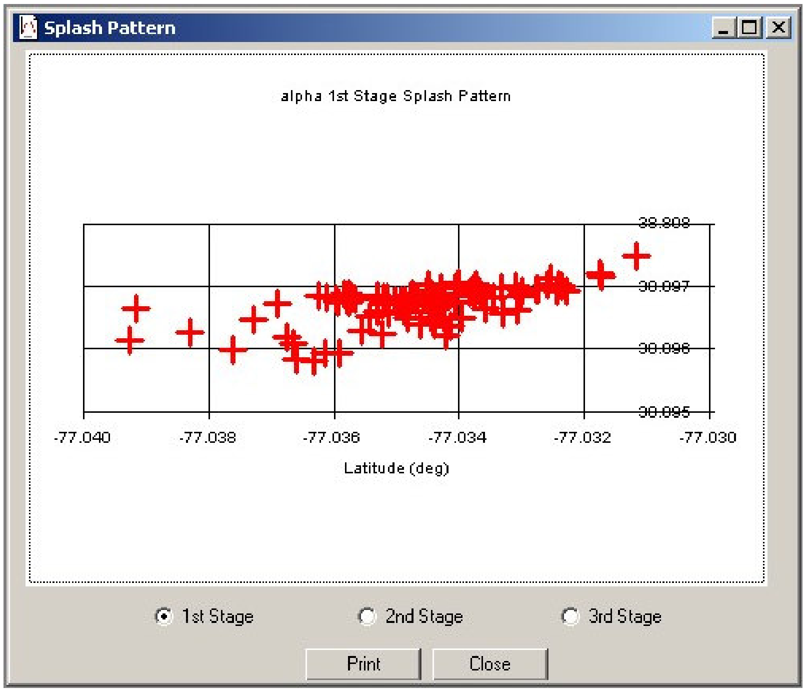
The remaining data streams are all ASCII text files of fixed column width for easy import into spreadsheets and other data processing applications. But while these text files are designed for easy import into other applications, the Splash GUI does include it's own (albeit limited) capability to quickly examine these text files in a graphical environment. Each of these text files and the Splash GUI interface for examining them is discussed below.

Splash Pattern Files/Window

As one may imagine, the splash pattern data file contains the impact locations (longitude and latitude) for each stage for each Assuming a scenario base filename of "alpha," the splash pattern data file will be named "spash_spl.out". A crudely formatted graphical representation of this data may be viewed by selection "Splash Pattern" from the "Output" pull-down menu at the top of the Splash GUI's main window.

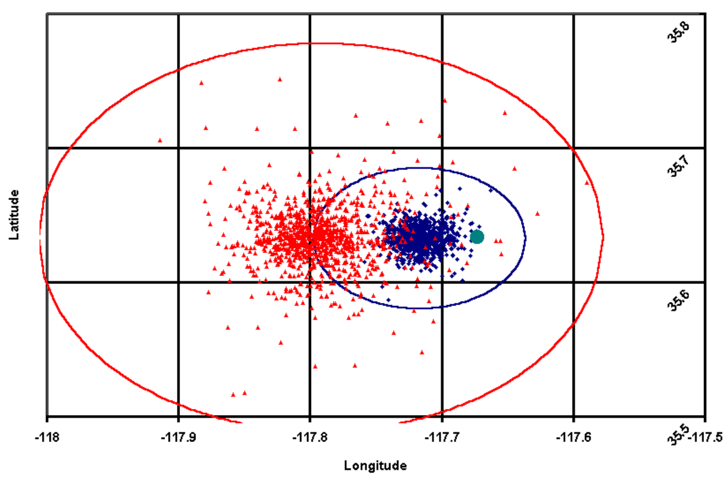
Those who endeavor to import the data in the splash pattern file into other applications no doubt harbor a desire to know the exact formatting of the splash pattern file. In tabular format, the columns found with the splash pattern data file are as follows:

Column	Description
Run	The iteration or run number. While most runs include the randomization required of a Monte-Carlo analysis, it should be noted that the 0^{th} run does not include any randomization. In other words, the 0^{th} run is the nominal trajectory.
1Longitude	Longitude of the 1^{st} stage impact point in degrees. A negative angle corresponds to West longitude.
1Latitude	Latitude of the 1^{st} stage impact point in degrees. A negative angle corresponds to South latitude.
2Longitude	Longitude of the 2^{nd} stage impact point in degrees. A negative angle corresponds to West longitude.
2Latitude	Latitude of the 2^{nd} stage impact point in degrees. A negative angle corresponds to South latitude.
3Longitude	Longitude of the 3^{rd} stage impact point in degrees. A negative angle corresponds to West longitude.
3Latitude	Latitude of the 3^{rd} stage impact point in degrees. A negative angle corresponds to South latitude.



The Splash Pattern window displaying a 100 impact scenario.

The author concedes, however, that for presentation quality graphics, the user is likely to be better off importing the data from the trajectory file(s) into a dedicated data processing application or spreadsheet.



An Excel plot displaying splash pattern data for 1000 flights of a boosted dart. Blue diamonds denote impact point for the booster. Red triangles denote impact points for the dart. Similarly the blue oval represents a 3-sigma oval for the booster while the red circle represents a 3-sigma oval for the dart. The green dot denotes the launch point.

Trajectory Data Files/Window

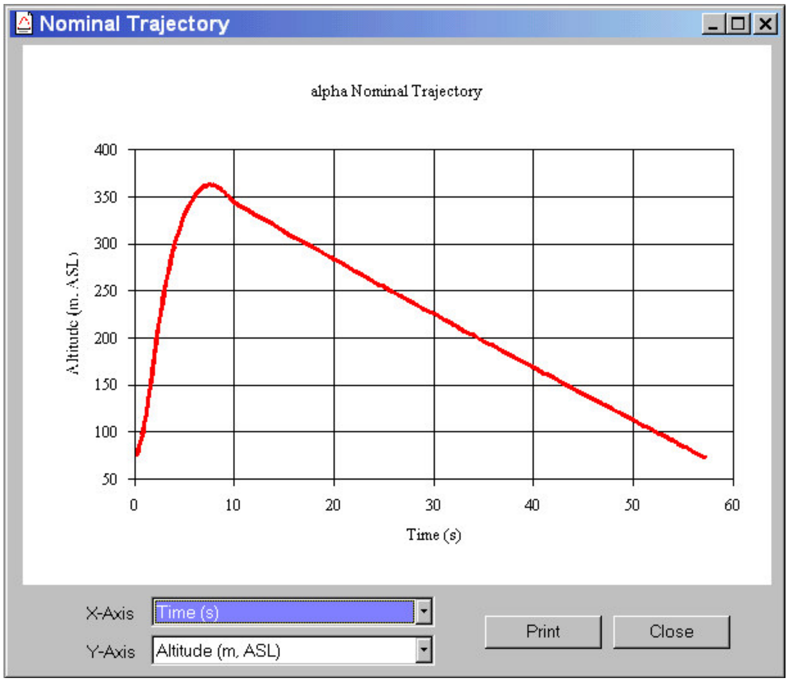
Splash generates anywhere from two to four trajectory files. These files contain the flight parameters for the nominal mission[12] outlined in the input windows. One file is produced for each stage (1-3) and an additional file is generated that tracks the "topmost" active stage (I.E., generates a single nominal trajectory based on the trajectories of all activated stages.).

Each trajectory file tracks a total of 33 parameters. While more detailed discussion is found in the sections of the manual dedicated to the console application, it may suffice to say that the data tracked is the following (in tabular format):

Column	**Description**
Time	Total time elapsed since beginning of simulation (s).
Longitude	Longitude (deg).
Latitude	Latitude (deg).
Altitude	Altitude (m or ft, ASL).
Azmth	Body azimuth (deg).
Eleva	Body elevation (deg).
Roll	Body roll (deg).
AbsVel	Velocity with respect to the center of the Earth (m/s or ft/s).
RelVel	Velocity with respect to a point on the surface of the Earth at the same longitude and latitude as the vehicle (m/s or ft/s).
AirVel	Velocity with respect to the local air, i.e., air speed (m/s or ft/s).
YawRt	Yaw rate (deg/s).
PitRt	Pitch rate (deg/s).
RolRt	Roll rate (deg/s).
Gamma	Flight angle (deg).
Headg	Heading (deg).
Mach	Mach number.
AOA	Angle of attack (deg).
Axial	Axial aerodynamic force (N or lbf).
Ca	Axial aerodynamic force coefficient normalized to the vehicle's nominal frontal area.
Normal	Normal aerodynamic force (N or lbf).
Cn	Normal aerodynamic force coefficient normalized to the vehicle's nominal frontal area.
Mass	Total vehicle mass (kg or lbm).
Mdot	Combined mass flow rate (kg/s or lbm/s) through all 5 motor nozzles.
Thrust1	Thrust (N or lbf) generated by motor 1.
Thrust2	Thrust (N or lbf) generated by motor 2.
Thrust3	Thrust (N or lbf) generated by motor 3.
Thrust4	Thrust (N or lbf) generated by motor 4.
Thrust5	Thrust (N or lbf) generated by motor 5.
Prop1	Propellant (kg or lbm) remaining in motor 1.
Prop2	Propellant (kg or lbm) remaining in motor 2.
Prop3	Propellant (kg or lbm) remaining in motor 3.
Prop4	Propellant (kg or lbm) remaining in motor 4.
Prop5	Propellant (kg or lbm) remaining in motor 5.

[12] No failures, all mission parameters exactly as found in input files/windows.

As stated elsewhere, Splash also allows the user to get a quick glimse of the data found in the trajectory files in a graphical format. The plotting routines are accessed through the "Output" pull-down menu found at the top of the main Splash GUI window. The use of these routines is trivial and is reduced to selecting variables for the X and Y axis of a plot from pull-down menus found on the plotting window (see below).



A time/altitude plot viewed from within the Splash GUI's data plotting interface.

The author concedes, however, that for presentation quality graphics, the user is likely to be better off importing the data from the trajectory file(s) into a dedicated data processing application or spreadsheet.

The Console Application

Description

The heart and soul of Splash is a console application that may be run independent of the GUI. While the console application is not as easy to use without the GUI, it allows the user to directly manipulate the simulation input files. In the author's experience, such direct manipulation often allows the user to simulate conditions not anticipated (and thus often not directly supported) by the original author. As a result direct manipulation of the data files and use of the console application is considered to be the modus operandi of the serious user. Thus, some discussion of this is in order.

Input Requirements

While many simulation packages include all data pertinent to a scenario in a single input file, Splash separates the data into two to five data files (depending upon the number of stages in the rocket) of 2 different classifications. The two different types of data files are as follows: scenario files and stage files. Each of these two file types will be discussed in detail, but first it is appropriate to outline some basic conventions that hold true for all Splash input files.

General Input Conventions

First and foremost, data files used by Splash are simple text files. While not as compact or as elegant as other file formats, text files allow for simple file manipulation and manual inspection for file accuracy. Historically, many simulation packages that utilize text data files have relied upon a very strict data formatting structure. While some rules must apply, every attempt has been made to make Splash input files easy to read for mere humans. As a result, the following may be said:

- Blank lines are ignored.
- Data is white space and/or comma delimited. In other words, data items within a single line are delimited by any number of commas, spaces, or tab spaces.
- The occurrence of an asterisk ("*") denotes that any remaining text on a given line are comments and to be ignored by Splash
- A single line of data is limited to 240 characters.

To better illustrate the conventions of data input, below are a number of examples of lines of data that are 100% equivalent within the context of Splash input files.

```
27.3  62610.0   0.008  * <-- That asterisk indicates comments!
27.3, 62.61e3,  8e-3   * Propelant(kg), It(N*s), Nozzle (m^2)
27.3,,62610,   .008   * Propelant, It, Nozzle Exit Area
  27.3 62610     8E-3   * Are we getting the picture?
```

Each data file's name must also conform to a standard naming convention. Again, the details of each file will be discussed later, but suffice to say that the names are all variations of a single file name referred to as the "base file name".

In addition to the conventions listed above, scenario and stage data files employ the use of "data blocks." Data blocks are small clusters of data to break down the file into more intuitive, easier to use chunks of data. For example, each stage data file contains a propulsion system data block. As one might guess, the this data block contains all data pertaining to the rocket motors for that particular stage. While data within each individual data block must be found in a particular order, it should be noted that the order

data blocks appear in a file is unimportant. This means that one may place often-modified data blocks at the top of a file to facilitate faster modification due to the ease of finding the desired block in a text editor.

Scenario Files

Scenario data files contain all information required to set up a launch that is *not* related to the rocket itself. In other words, scenario data files contain information on the launch rail, the weather, the local terrain, and any uncertainties.

Scenario data files are identified by a file extension of ".scn". In other words, if the base file name is "alpha", the corresponding scenario data file must be named " alpha.scn".

A description of each data block (listed in alphabetical order) found in the scenario data file is as follows:

Rail Data Block

As it's name implies, the rail data block contains all information pertinent to the launch rail. The format of the rail data block is as follows:

Line	Contents
1	Must contain the pneumonic "RAIL".
2	Must contain 3 numeric arguments. In order, they are the launch rail's longitude (degrees), latitude (degrees), and altitude (meters, ASL). Note that West longitude is denoted as a negative angle while South latitude is likewise considered a negative angle.
3	Must contain 3 numeric arguments. In order they are the launch rail's azimuth (degrees), elevation (degrees), and length (meters). Note that the convention used within Splash dictates that a negative elevation is pointing "up".
4	Must contain 1 numeric argument. This argument is the initial velocity of the rocket in meters per second. Most of the time this argument will be set to zero, but the user was left with the option of non-zero initial velocities to crudely model a gun-launched rocket or similar system that may have a non-negligible velocity at motor ignition.
5	Must contain the data block termination string, "-----".

A sample rail data block may be seen below. This data indicates that a rocket is to be launched due East and at an elevation angle of 80 degrees (10 degrees off vertical) from the author's backyard in Southern California. The launch rail is 10 meters long and the initial velocity is 0 meters per second.

```
RAIL
-117.6726  35.6337 728.2  * Longitude, Latitude, Altitude (ASL)
  90.0    -80.0     10.0  * azimuth, elevation, rail length
   0                      * velocity
-----
```

Terrain Data Block

The terrain data block does nothing more than define the local terrain's altitude above sea level in the landing zone. For most cases, the local terrain and the launch rail will be at the same altitude, but Splash allows the user to define separate altitudes for the launch and impact areas. The most obvious use of this feature is to crudely simulate an air launch, but it may find use in terrestrial launches as well to simulate other exotic systems. Note that a rocket has been deemed to impact the Earth when it's altitude falls below the terrain altitude *and* it's flight angle (gamma) indicates the rocket is in a dive. The format of the terrain data block is as follows:

Line	Contents
1	Must contain the pneumonic "TERRAIN".
2	Must contain a single numeric argument. This argument defines the altitude of the impact area in meters above sea level.
3	Must contain the data block termination string, "-----".

Although they are very simple, a sample terrain data block is shown below for completeness.

```
TERRAIN
728   * Local terrain is about 2300 feet ASL
-----
```

Uncertainty Data Block

Uncertainty data blocks contain information on all parameters that are to be modified in the generation of the splash pattern. The format of the splash data file is as follows:

Line	Contents
1	Must contain the pneumonic "UNCERTAINTY".
2	Contains the total number of iterations desired. For mission planning, 1 is all you will want, but for a full-blown splash pattern to be submitted to the FAA as part of a launch license application 5,000 – 10,000 are probably better numbers.
3	Contains the launch mass 1-sigma uncertainty as a percentage of the total mass.
4	Contains the 1-sigma uncertainty of the moments of inertia as a percentage of the moment of inertia for the axis in question.
5	Contains the 1-sigma uncertainty of the location of the center of gravity as a number of calibers.
6	Contains the 1-sigma uncertainty in axial aerodynamic force coefficient (Ca) as a percentage.
7	Contains the 1-sigma uncertainty in normal aerodynamic force coefficient (Cn) as a percentage.
8	Contains the 1-sigma uncertainty of the location of the center of pressure as a number of calibers.
9	Contains the 1-sigma uncertainty of the fin cant angle in degrees.
10	Contains the 1-sigma uncertainty of each rocket motor's total impulse as a percentage of the total impulse.
11	Contains the 1-sigma uncertainty of the propellant mass for each rocket motor as a percentage of said mass.
12	Contains the 1-sigma uncertainty for each motor's thrust alignment (i.e., thrust misalignment) in degrees.
13	Contains the probability of an ignition failure for each motor as a percentage. 0 indicates a 100% reliable ignition, 100 indicates a 100% likelihood of ignition failure.
14	Contains the probability of a catastrophic failure (CATO) for each motor as a percentage. Note that if any motor CATOs it is assumed that all other motors in the same stage suffer a similar failure due to debris impact.
15	Contains the probability of a failure to deploy[13] the recovery system as a percentage.
16	Contains the probability of a parachute/vehicle separation[14] as a percentage.
17	Contains the 1-sigma uncertainty for wind velocity in meters per second.
18	Contains the 1-sigma uncertainty for wind direction in degrees.
19	Contains the 1-sigma uncertainty for launch rail azimuth in degrees.

[13] Commonly referred to as a "lawn dart".
[14] Commonly referred to as a "zipper".

20	Contains the 1-sigma uncertainty for launch rail elevation uncertainty in degrees.
21	Must contain the data termination string, "-----".

A sample uncertainty data block is shown below.

```
UNCERTAINTY
1000   * How many times do we want to play?
*MASS
3       * Mass                 (1 sigma uncertainty - percent)
2       * Moments of Inertia   (1 sigma uncertainty - percent)
0.25    * CG                   (1 sigma uncertainty - calibers)
*AERODYNAMIC
10      * Ca                   (1 sigma uncertainty - percent)
10      * Cn                   (1 sigma uncertainty - percent)
1       * CP                   (1 sigma uncertainty - calibers)
0.25    * Fin Cant Angle       (1 sigma uncertainty - degrees)
*PROPULSION
5       * Total Impulse        (1 sigma uncertainty - percent)
1       * Propellant Mass      (1 sigma uncertainty - percent)
0.25    * Thrust Misalignment  (1 sigma uncertainty - degrees)
*FAILURE
2       * Ignition             (failure likelihood - percent)
1       * CATO                 (failure likelihood - percent)
5       * Deployment Failure   (failure likelihood - percent)
10      * Chute Failure        (failure likelihood - percent)
*WEATHER
3       * Wind Velocity        (1 sigma uncertainty - mps)
10      * Wind Direction       (1 sigma uncertainty - degrees)
*RAIL
5       * Azimuth Error        (1 sigma uncertainty - degrees)
1       * Elevation Error      (1 sigma uncertainty - degrees)
-----
```

Weather Data Block

Again, the name of the data block is indicative of what data it contains. In this case, the data block contains the local atmospheric conditions. Wind conditions obviously affect weather cocking, but local barometric pressure and temperature effects density altitude which in turn effects lift, drag, and thrust generated by the rocket. The format for the weather data block is as follows:

Line	Contents
1	Must contain the pneumonic "WEATHER".
2	Must contain 2 numeric arguments. In order they are the launch site's current barometric pressure (mmHg) and temperature (^{o}C). If the current barometric pressure is unknown or if the user simply wishes to use a standard atmosphere, a negative value for barometric pressure will turn off atmospheric corrections.
3	Must contain at least 2 and no more than 24 numeric arguments. These arguments are a list of altitudes (m ASL) for which corresponding wind direction data (see line 4) is valid.
4	Must contain the same number of numeric arguments as line 3. As previously mentioned, these arguments define the direction (degrees) in which the wind is coming *from*. 0 degrees indicates a wind from the North, 90 degrees represents a wind from the East, and so on. Note that it is good practice to make the last 2 arguments identical to avoid any unchecked extrapolation in the event the vehicle exits the defined weather

	patterns.
5	Must contain at least 2 and no more than 24 numeric arguments. These arguments are a list of altitudes (m ASL) for which corresponding wind velocity data (see line 6) is valid. Note that in practice lines 3 and 5 will most likely be identical but there is nothing in Splash programming logic that dictates this.
6	Must contain the same number of numeric arguments as line 5. As previously mentioned, these arguments define the velocity (m/s) of the wind. As with line 4, it is good practice to make the last 2 arguments identical to avoid any unchecked extrapolation in the event the vehicle exits the defined weather patterns.
7	Must contain the data block termination string, "-----".

A sample weather data block may be seen below.

```
WEATHER
* A hot day with low level winds from
* the N and high level winds from the NNE.
760  43.5
0 1e3 2e3  5e3 10e3 20e3 21e3
0   0   0 23.5 22.5 22.5 22.5
0 1e3 2e3  5e3 10e3 20e3 21e3
1   2   3    5   20   25   25
-----
```

Stage Files

Stage data files describe all parameters that are included within the vehicle itself. This includes all aerodynamic and propulsion performance as well as information regarding staging and recovery. If a full-up rocket incorporates more than one stage, then a stage data file is required for each stage (The maximum number of stages is 3.).

Stage data files are identified by a file extension of ".stg", but the naming of a stage data file is not just a matter of appending ". stg" to the base file name as would be expected given the naming conventions of the scenario and splash data files. Rather, the stage number *and* ".stg" must be appended to the base file name. In other words, if the base file name is "alpha", the corresponding stage data file for a first stage must be named "alpha1.stg". Similarly, the stage data file for the second stage is "alpha2.stg" and the stage data file for the third stage is "alpha3.stg".

As with the scenario data file, a stage data file is further subdivided into data blocks. These data blocks may appear in any order within the stage data file, but all must appear. The format of each of these data blocks is discussed below (in alphabetical order).

Axial Force Data Block

As one may imagine, the axial force data block contains information on the thrust-off axial force. Most simulation packages store a list of axial force coefficients (Ca's) for direct use in axial force calculations; Splash, on the other hand, uses lists of coefficients of a polynomial that is in turn used to calculate an axial force coefficient. In other words, Splash calculates the axial force coefficient by using an equation of the form…

$$C_a = A + B * AOA + C * AOA^2$$

$$\begin{aligned} &\text{where :} \\ &\quad C_a = \text{axial force coefficient (degrees)} \\ &\quad A, B, C = \text{polynomial coefficients} \\ &\quad AOA = \text{angle of attack} \end{aligned}$$

Extreme care should be used when selecting the values for A, B, and C in the above equation as poorly selected values will yield wildly inaccurate simulation results. More to the point, one should ensure that the values selected for A, B, and C produce a Ca of 0.0 at an angle of attack of 90 degrees.

While this methodology provides a smooth curve for Ca over a broad range of angles of attack with minimal user input, it neglects the fact that axial force coefficients depend on Mach number. For this reason, Splash employs not one set of coefficients, but a family of coefficients.

The format for the axial force data block is as follows:

Line	Contents
1	Must contain the pneumonic "CA".
2	Must contain the axial force "multiplier". This is a number by which the final axial force is multiplied. Usually the value of this number is 1.0, but any number can be used in the course of sensitivity studies. For example, if the user wishes to increase axial force by 10% in an attempt to see what would happen, he need only input 1.1 as the multiplier rather than generate a new drag curve.
3	Must contain at least 2 but no more than 24 numeric arguments. These arguments are the Mach numbers for which the axial force coefficients (see lines 4-6) are valid.
4	Must contain at least 2 but no more than 24 numeric arguments. These arguments are the 0th order axial force coefficients corresponding to the Mach numbers listed in line 3.
5	Must contain at least 2 but no more than 24 numeric arguments. These arguments are the 1st order axial force coefficients corresponding to the Mach numbers listed in line 3.
6	Must contain at least 2 but no more than 24 numeric arguments. These arguments are the 2nd order axial force coefficients corresponding to the Mach numbers listed in line 3.
7	Must contain the data block termination string, "-----".

A sample axial force data block may be seen below, notice that the first row of coefficients (the "A" row) are simply the zero lift axial force coefficients which are equivalent to zero lift drag coefficients.

```
CA  * For each Mach:  Ca(AOA) = A + B*AOA + C*AOA^2
1.0
   0.2   0.8    1.2   1.75    2.5     3.5   * Mach
  0.97  0.91   1.66   1.42    1.27   1.11   * A
-0.035 0.015 -0.086 -0.022  -0.024  -0.010  * B
0.0027  7e-4 0.0047 0.0014  0.0020  0.0011  * C
-----
```

Base Drag Data Block

The base drag data block is nothing more than a one dimensional look up table of base drag coefficients (the portion of a vehicle's zero lift drag [15] that is due to drag at the base of the vehicle). This data is used to calculate the difference in axial force between thrust on and off conditions.

[15] At zero angle of attack, drag and axial force are identical.

Note that one should ensure that the actual base drag coefficient is used; some aeroprediction codes produce a base pressure coefficient. A base pressure coefficient is *not* the same thing as a base drag coefficient. If in doubt, entry of zeros is probably the best bet.

The format of the base drag data block is as follows:

Line	Contents
1	Must contain the pneumonic "CB".
2	Must contain at least 2 but no more than 24 numeric arguments. These arguments are the Mach numbers for which the base drag coefficients (see line 3) are valid for.
3	Must contain at least 2 but no more than 24 numeric arguments. These arguments are the base drag coefficients corresponding to the Mach numbers listed in line 2.
4	Must contain the data block termination string, "-----".

A sample base drag data block is shown below.

```
CB
 0.2  0.8  0.9  1.0  1.2  1.4 1.75  2.5  3.5  * Mach
0.15 0.15 0.16 0.22 0.23 0.20 0.17 0.12 0.08  * Cb
-----
```

Center of Gravity Data Block

The center of gravity data block is nothing more than a one dimensional look up table listing the center of gravity (in calibers) and corresponding masses representative of various instants during a rocket's burn.

The format of the center of gravity data block is as follows:

Line	Contents
1	Must contain the pneumonic "CG".
2	Must contain at least 2 but no more than 24 numeric arguments. These arguments are the masses (kg) numbers for which the centers of gravity (see line 3) are valid for.
3	Must contain at least 2 but no more than 24 numeric arguments. These arguments are the centers of gravity corresponding to the masses listed in line 2.
4	Must contain the data block termination string, "-----".

A sample center of gravity data block is shown below. While this data block indicates a simple linear relationship between a launch mass and a burnout mass, there is no reason why a more complex relationship could not be used.

```
CG
58.2    85.5                    * Mass
12.0    11.4                    * CG/Dref
-----
```

Center of Pressure Data Block

As one may imagine, the center of pressure data block contains information on the center of aerodynamic pressure. Most simulation packages store a list of centers of pressure (CP's) for direct use in pitching moment calculations; Splash, on the other hand, uses lists of coefficients of a polynomial that is in turn used to calculate a center of pressure. In other words, Splash calculates the center of pressure by using an equation of the form…

$$
\begin{aligned}
&CP = A + B * AOA + C * AOA^2 \\
&\text{where :} \\
&\quad CP = \text{center of pressure (calibers)} \\
&\quad A, B, C = \text{polynomial coefficients} \\
&\quad AOA = \text{angle of attack}
\end{aligned}
$$

But while this equation provides a smooth center of pressure movement with a minimum of input requirements, it neglects the fact that the center of pressure also depends on Mach number. For this reason, Splash employs not one set of coefficients, but a family of coefficients.

The format for the axial force data block is as follows:

Line	Contents
1	Must contain the pneumonic "CP".
2	Must contain a single numeric argument, the center of pressure (CP) offset. The CP offset provides a simple way for the user to vary the CP as one may during the course of a sensitivity study. While a nominal CP is calculated as described previously, the CP offset is added to this value to move the CP fore or aft as desired. For example, if the user wishes to move the CP back one caliber, the CP offset should be 1.0. Similarly, if the user wishes to move the CP foreward 0.5 calibers, the CP offset should be –0.5. Obviously, 0.0 is the value normally selected.
3	Must contain at least 2 but no more than 24 numeric arguments. These arguments are the Mach numbers for which the center of pressure coefficients (see lines 3-5) are valid.
4	Must contain at least 2 but no more than 24 numeric arguments. These arguments are the 0th order normal force coefficients corresponding to the Mach numbers listed in line 3.
5	Must contain at least 2 but no more than 24 numeric arguments. These arguments are the 1st order normal force coefficients corresponding to the Mach numbers listed in line 3.
6	Must contain at least 2 but no more than 24 numeric arguments. These arguments are the 2nd order normal force coefficients corresponding to the Mach numbers listed in line 3.
7	Must contain the data block termination string, "-----".

A sample center of pressure data block may be seen below.

```
CP     * For each Mach:  CP(AOA) = A + B*AOA + C*AOA^2
0.0
 0.2   0.5   0.9   0.95   1.05    1.1   * Mach
  14    14    14     13     13     13   * A
0.01  0.01  0.01   0.01   0.01   0.01   * B
 0.0   0.0   0.0    0.0    0.0    0.0   * C
-----
```

Fin Data Block

While the overall aerodynamic properties of the vehicle are primarily contained within the other data blocks, the fin data block, while obviously containing information on the vehicle's fins, is concerned with vehicle yaw/pitch damping and roll[16] and does not effect simple axial or normal force calculations.

[16] Splash uses some non-standard methodologies that appear to yield reasonable results while reducing the degree of sophistication required of the user in producing input data.

Before line-by-line discussion of the format of the fin data block, it should be noted that several lines of the fin data block are devoted to defining the normal force coefficient of a single fin. The method in which these coefficients are calculated is identical to that used in the Axial Force Data Block to calculate axial force coefficients. The fin normal force coefficients are not, however, used to calculate axial or normal forces experienced by the vehicle; they are used strictly for calculations involving yaw/pitch damping and roll moments. For this reason, it is not terribly important to have exact numbers and in fact, the numbers listed in the sample file may be sufficiently accurate for most applications.

The format for the fin data block is as follows:

Line	Contents
1	Must contain the pneumonic 'FINS".
2	Must contain an integer defining the number of fins the rocket has. Note that while program logic will allow for any number of fins, realistically the methods employed in Splash dictate that no more than 6 fins be used.
3	Must contain a numeric argument defining the planer area of a single fin as multiple of the cross sectional area of the vehicle. While obviously a non-standard nomenclature, this method allows the scaling of vehicles up or down with a minimum of hassle.
4	Must contain two numeric arguments. The first of these arguments is the longitudinal location of the fin's center of pressure measured as the number of vehicle calibers from the vehicle's nose. The second argument is the radial location of the fin's center of pressure, again measured in calibers.
5	Must contain a single argument, the fin cant angle measured in degrees.
6	Must contain at least 2 but no more than 24 numeric arguments. These arguments are the Mach numbers for which the fin normal force coefficients (see lines 7-9) are valid.
7	Must contain at least 2 but no more than 24 numeric arguments. These arguments are the 0th order normal force coefficients corresponding to the Mach numbers listed in line 6.
8	Must contain at least 2 but no more than 24 numeric arguments. These arguments are the 1st order normal force coefficients corresponding to the Mach numbers listed in line 6.
9	Must contain at least 2 but no more than 24 numeric arguments. These arguments are the 2nd order normal force coefficients corresponding to the Mach numbers listed in line 6.
10	Must contain the data termination string "-----".

A sample fin data block may be seen below. This data block, with the exception of lines 2-4, may very well represent sufficiently accurate data for all the rockets the user ever desires to model.

```
FINS                  * Polynomial is for FIN Cns
4                     * number of fins
6                     * FinArea/Aref
22   1                * CPx, CPr (in calibers)
0.0                   * cant angle
  0.0     0.8     1.4     1.75    2.5     3.5         * Mach
   0       0       0       0       0       0          * A
  0.022   0.022   0.022   0.022   0.022   0.022       * B
 -1.2e-4 -1.2e-4 -1.2e-4 -1.2e-4 -1.2e-4 -1.2e-4      * C
-----
```

General Information Data Block

The general information data block contains a mixture of basic mass and geometry information and staging information.

While the mass and geometry data is largely self-explanatory, the staging information is complex in nature and unique to Splash. As a result, there is a discussion of staging criterion and formatting in the section entitled 'Staging and Recovery Criterion Explained."

The format of the general information data block is as follows:

Line	Contents
1	Must contain the pneumonic 'GENERAL".
2	Must contain three numeric arguments. In order these arguments are the rocket's launch mass (kg), length (m), and reference diameter (m).
3	Must contain the first line of the staging criterion. As stated previously, staging criterion will be discussed in detail in a later section of this manual.
4	Must contain the second line of the staging criterion.
5	Must contain the third line of the staging criterion.
6	Must contain the data block termination string "-----".

A sample general information data block is shown below.

```
GENERAL
85.5  22.8  0.13    * Mass, length, diameter(Dref)
T >     6           * Staging criterion line 1
G >     0           * Staging criterion line 2
A <  1000           * Staging criterion line 3
-----
```

Inertial Tensor Data Block

While the contents of the inertial tensor data block may be intuitively obvious to some, it may not be so obvious to others. For those without a background in 6DOF systems, the inertial tensor is nothing more than a matrix that contains all the moments and products of inertia[17] for a physical object.

The vehicle-based coordinate system used by Splash for the inertial tensor (and everything else) is as follows:

Axis	Plain English Equivalent
X	Forward
Y	Port (left)
Z	Up

The format of the inertial tensor is as follows:

Line	Contents
1	Must contain the pneumonic 'INERTIA".
2	Must contain the gross vehicle mass (kg) at which the moment and products of inertia calculations (lines 3-6) were made. This need not be the launch or burnout mass of the vehicle.
3	Must contain three numeric arguments. In order these arguments are Ixx (m^4), Ixy (m^4), and Ixz (m^4).
4	Must contain three numeric arguments. In order these arguments are Iyx (m^4), Iyy (m^4), and Iyz (m^4).
5	Must contain three numeric arguments. In order these arguments are Izx (m^4), Izy

[17] If the user is unfamiliar with these terms, the author recommends researching them on the internet as proper treatment of these topics would take more space than the author is willing to dedicate in these pages.

	(m^4), and Izz (m^4).
6	Must contain the data block termination string, "-----".

A sample inertial tensor data block is shown below.

```
INERTIA
80
.2      0      0           * Ixx, Ixy, Ixz
0      62      0           * Iyx, Iyy, Iyz
0       0     62           * Izx, Izy, Izz
-----
```

Normal Force Data Block

As one may imagine, the normal force data block contains information about the aerodynamic normal force. Most simulation packages store a list of normal force coefficients (Cn's) for direct use in normal force calculations; Splash, on the other hand, uses lists of coefficients of a polynomial that is in turn used to calculate a normal force coefficient. In other words, Splash calculates the normal force coefficient by using an equation of the form…

$$C_n = A + B * AOA + C * AOA^2$$

$$\text{where :}$$

$$C_n = \text{normal force coefficient (degrees)}$$

$$A, B, C = \text{polynomial coefficients}$$

$$AOA = \text{angle of attack}$$

But while this equation provides a smooth normal force curve with a minimum of input requirements, it neglects the fact that normal force coefficients depend on Mach number. For this reason, Splash employs not one set of coefficients, but a family of coefficients.

The format for the axial force data block is as follows:

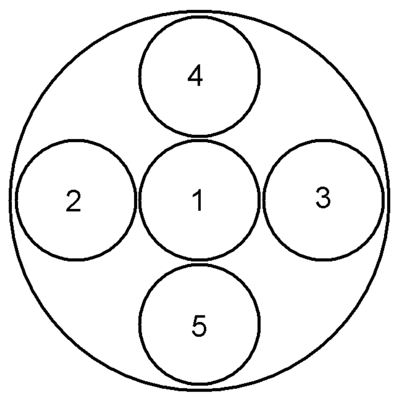
Line	Contents
1	Must contain the pneumonic 'CN".
2	Must contain the normal force "multiplier". This is a number by which the final normal force is multiplied. Usually the value of this number is 1.0, but any number can be used in the course of sensitivity studies. For example, if the user wishes to increase normal force by 10% in an attempt to see what would happen, he need only input 1.1 as the multiplier rather than generate a new drag curve.
3	Must contain at least 2 but no more than 24 numeric arguments. These arguments are the Mach numbers for which the normal force coefficients (see lines 4-6) are valid.
4	Must contain at least 2 but no more than 24 numeric arguments. These arguments are the 0th order normal force coefficients corresponding to the Mach numbers listed in line 3.
5	Must contain at least 2 but no more than 24 numeric arguments. These arguments are the 1st order normal force coefficients corresponding to the Mach numbers listed in line 3.
6	Must contain at least 2 but no more than 24 numeric arguments. These arguments are the 2nd order normal force coefficients corresponding to the Mach numbers listed in line 3.
7	Must contain the data block termination string, "-----".

A sample normal force data block may be seen below.

```
CN   * For each Mach:  Cn(AOA) = A + B*AOA + C*AOA^2
1.0                                         * Cn fudge factor
  0.0   0.8    1.4   1.75    2.5     3.5                 * Mach
    0     0      0      0      0       0                 * A
 0.51  0.40   0.32   0.36   0.28    0.28                 * B
0.019 0.022  0.027  0.024  0.022   0.018                 * C
-----
```

Propulsion System Data Block

Obviously, the propulsion system defines the rocket motors driving the vehicle's flight. What is not obvious, however, is the fact that each stage is assumed to possess five rocket motors. No more. No less. The motors are arranged in a manner similar to the five F-1's found on the Saturn V. Those who are not up on their rocketry history may instead refer to the sketch of the motor arrangement found below.



As seen from the aft end, the layout of the five rocket motors found in each stage.

But not every vehicle has five motors; how is such a configuration suited to simulate vehicles with fewer than five motors? In two words: null motors. While all five motors exist in program logic, there is nothing in said logic that mandates these motors to provide any thrust or even have any propellant in them. Thus, "excess" motors do not actually affect the vehicle's flight in any way shape or form.

The format of the propulsion system data block is as follows:

Line	Contents
1	Must contain the pneumonic "MOTORS".
2	Contains a string of up to 240 non-white space characters. This string is used by the GUI to identify the motor but the 6DOF program logic does not use the string as anything other than a placeholder (Which means that this line can *not* be left blank!).
3	Contains a single numeric argument. This argument represents a delay (in seconds after stage separation/activation) before the motor is ignited. Generally this value will be set to zero, but users who employ air-started motors or significant delays before motor ignition after stage separation will find this feature useful.
4	Contains a single numeric argument. This argument represents the off-centerline distance (in calibers) of the motor's thrust axis. For the #1 motor (see diagram of motor configuration) this number should always be zero. Similarly, it should always be non-zero for the remaining four motors.
5	Contains three numeric arguments. These arguments (in order) are the motor's propellant mass (kg), *sea level* total impulse (N*s), and nozzle exit area (m^2).
6	Must contain at least 3 but no more than 24 numeric arguments. These arguments are

	a list of times (s) measured from motor ignition that correspond to thrust values listed in line 7. Note that the first argument should always be 0.
7	Must contain at least 3 but no more than 24 numeric arguments. These arguments are a list of instantaneous thrust levels (N) that correspond to the times listed in line 6. The first and last of the listed thrusts should always be 0.
8	Must contain the data block termination string "-----".
9-15	Identical in format to lines 2-8, but concerning motor number 2.
16-22	Identical in format to lines 2-8, but concerning motor number 3.
23-29	Identical in format to lines 2-8, but concerning motor number 4.
30-36	Identical in format to lines 2-8, but concerning motor number 5.

It should at this time be noted that the thrust/time curve entered is scaled such that a simple trapezoidal integration of the scaled thrust/time curve will precisely match the user-defined total impulse.

Below is a sample propulsion system data block. It represents a 2 motor cluster of N class motors. Notice that motors 1, 4, and 5, while still in the data file provide no input to vehicle performance, as they have no propellant, total impulse, or nozzle exit area.

```
MOTORS
Motors/Null.EDX                        * Type
0.0                                    * Ignition delay
0.0                                    * Off-centerline distance
0.0  0.0  0.0                          * Propellant, It, Aexit
0.0  1.0  1.0                          * Time
  0    1    0                          * Thrust
-----
Motors/Custom1.EDX                     * Type
0.0                                    * Ignition delay
0.25                                   * Off-centerline distance
13.5  31610   4e-3                     * Propellant, It, Aexit
0.0 0.01 0.13 0.23 1.12 2.24 4.16 4.96 6.14  * Time
  0 2343 2003 1870 1310 1354 1434  450    0  * Thrust
-----
Motors/Custom1.EDX                     * Type
0.0                                    * Ignition delay
0.25                                   * Off-centerline distance
13.5  31610   4e-3                     * Propellant, It, Aexit
0.0 0.01 0.13 0.23 1.12 2.24 4.16 4.96 6.14  * Time
  0 2343 2003 1870 1310 1354 1434  450    0  * Thrust
-----
Motors/Null.EDX                        * Type
0.0                                    * Ignition delay
0.25                                   * Off-centerline distance
0.0  0.0  0.0                          * Propellant, It, Aexit
0.0  1.0  1.0                          * Time
  0    1    0                          * Thrust
-----
Motors/Null.EDX                        * Type
0.0                                    * Ignition delay
0.25                                   * Off-centerline distance
0.0  0.0  0.0                          * Propellant, It, Aexit
0.0  1.0  1.0                          * Time
  0    1    0                          * Thrust
-----
```

Recovery System Data Block

The recovery system data block does exactly what one would assume it does; it defines the recovery system. More to the point, the recovery system data block contains information on the deployment and subsonic drag characteristics of the recovery system. Notice that the words "recovery system" are used and not "parachute." This is because Splash does not spend a lot of time doing detailed modeling of the recovery system. It would thus be somewhat misleading to state that Splash models a parachute. Nonetheless, the vehicle slows to the appropriate descent rate and even swings from side to side, much as a rocket under a parachute would. In other words, it does a good enough job for the task at hand.

While some of the data contained in this data bock is virtually self-explanatory, the deployment information is complex in nature and unique to Splash. As a result, there is a discussion of deployment criterion and formatting in the section entitled "Staging and Recovery Criterion Explained."

The format of the recovery system data block is as follows:

Line	Contents
1	Must contain the pneumonic "RECOVERY".
2	Must contain two numeric arguments. In order these arguments are the recovery system's subsonic drag coefficient, and nominal diameter [18] (m).
3	Must contain the first line of the deployment criterion. As stated previously, staging criterion will be discussed in detail in a later section of this manual.
4	Must contain the second line of the deployment criterion.
5	Must contain the third line of the deployment criterion.
6	Must contain the data block termination string "-----".

Staging and Recovery Criterion Explained

Within the general information and recovery system data blocks, there exist six lines of data that have until now been unexplained. As these lines are collectively referred to as the staging and deployment criterion, it is obvious that these lines control exactly when and where a vehicle stages or deploys it's recovery system.

Exactly how these lines control staging (and deployment) is actually quite simple. The staging criterion is a collection of three logical tests that must be satisfied in order. Each test is a relatively simple numerical comparison between a given simulation parameter (altitude, time, etc.) and a user-specified trigger value. When the first test is found to be true, Splash begins to examine the second test. When the second test is found to be true, Splash begins to examine the third test. When the third test is found to be true, Splash separates the upper stage or deploys the recovery system as appropriate[19].

While some examples will be shown shortly, it would be logical to first list the simulation parameters available to the user for staging/deployment. The simulation parameters currently supported by Splash for use in staging/deployment are:

Parameter	Description
A	Altitude. Trigger value units are meters above sea level. This parameter is most likely useful to those using barometer-based deployment devices or a 6DOF inertial measurement unit (IMU).
a	Change in altitude. Trigger value units are meters.
E	Body elevation angle (sometimes referred to as "theta"). Trigger value units are degrees. By convention, -90 degrees specifies a vehicle pointing "straight up"

[18] Assume a single parachute of circular section.

[19] Note that a booster stage is allowed to separate from the sustainer and deploy a recovery system. These events are completely independent of each other.

	while a +90 degrees specifies a vehicle pointing "straight down". When using deployment devices such as horizon detectors, this is most likely the parameter one should use.
e	Change in body elevation angle.
G	Flight angle (sometimes referred to as "gamma"). . Trigger value units are degrees. By convention, -90 degrees specifies a velocity vector pointing "straight up" while a +90 degrees specifies a velocity vector pointing "straight down". This parameter is most likely useful to those using barometer-based deployment devices or a 6DOF inertial measurement unit (IMU).
g	Change in flight angle.
I	Immediate. This parameter does not actually track any simulation variables. The test in question is immediately valued as true and the simulation moves on to the next criterion test line. Note that the direction and trigger values are still required as place holders, but do not actually have any effect on simulation behavior.
M	Mach number. Trigger value is unitless. This parameter should only be used if the vehicle in question utilizes a barometric unit.
m	Change in Mach number.
N	Never. This parameter does not actually track any simulation variables. The test in question is perpetually valued as false and the simulation never moves on to the next criterion line (and thus never stages/deploys). Note that the direction and trigger values are still required as place holders, but do not actually have any effect on simulation behavior.
P	Atmospheric pressure. Trigger value units are Pascals. Obviously, this parameter should only be used if the vehicle in question utilizes a barometric unit.
p	Change in atmospheric pressure.
Q	Dynamic pressure (often referred to as "Q"). Trigger value units are Pascals. Obviously, this parameter should only be used if the vehicle in question utilizes a pitot tube in conjunction with a barometric unit.
q	Change in dynamic pressure.
T	Time. Trigger value units are seconds. This parameter should be used when the vehicle in question utilizes a clock or pyrotechnic delay for staging/deployment.
t	Change in time.

Examples of possible user-desired scenarios and the corresponding staging/deployment criterion may be seen below.

Desired Profile	**Criterion Lines**

Fly for a total of 10 seconds.
Stage/deploy.
	`T > 10.0`
	`I > 0.0`
	`I > 0.0`

Fly until missile "noses over" past horizontal.
Wait for missile to descend below 1000 m ASL.
Stage/deploy.
	`E > 0.0`
	`A < 1000`
	`I > 0.0`

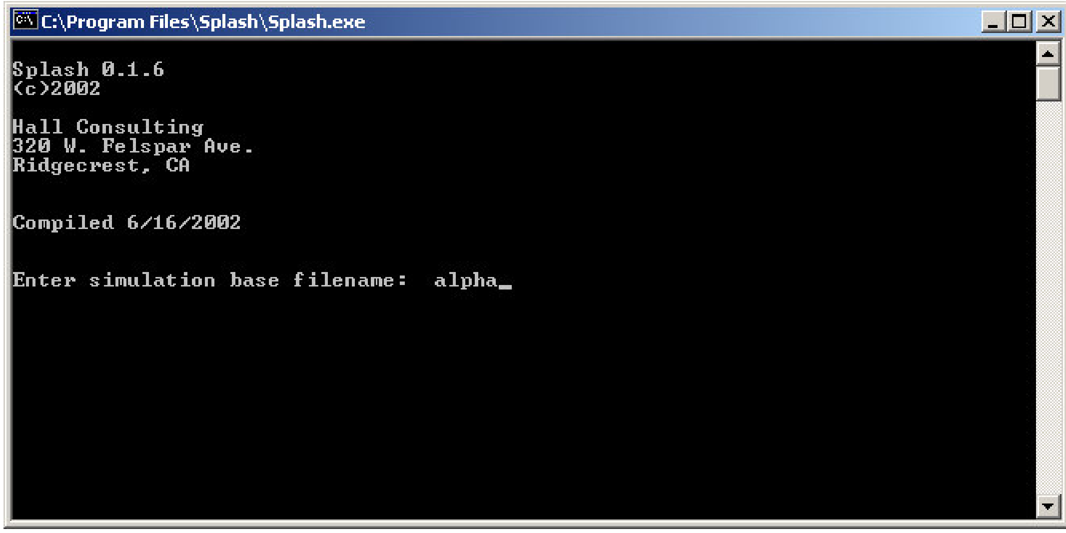
Fly to apogee.
Wait three seconds.
Stage/deploy.
	`G > 0.0`
	`t > 3.0`
	`I > 0.0`

At this point the user may have noticed that in the above examples the third test of the staging/deployment criterion is always "I > 0.0". This has nothing to do with program logic. Rather, it is representative of the fact that two tests will most likely provide all the functionality required for 99% of the users out there. The third test was included to incorporate that last 1% of users who may have more complex requirements for staging/deployment timing.

Execution

Execution of the console application is trivial. From Windows, the user need only double click the Splash console application executable. At this time, Splash will prompt the user for the base filename for the scenario required. The base filename should be entered sans any extensions (".scn", ". stg", etc.). For example, if the input data files for a particular scenario are "alpha.scn" and "alpha1.stg", then the user should enter the base filename of "alpha".

That's it. After base filename entry Splash will do its thing.



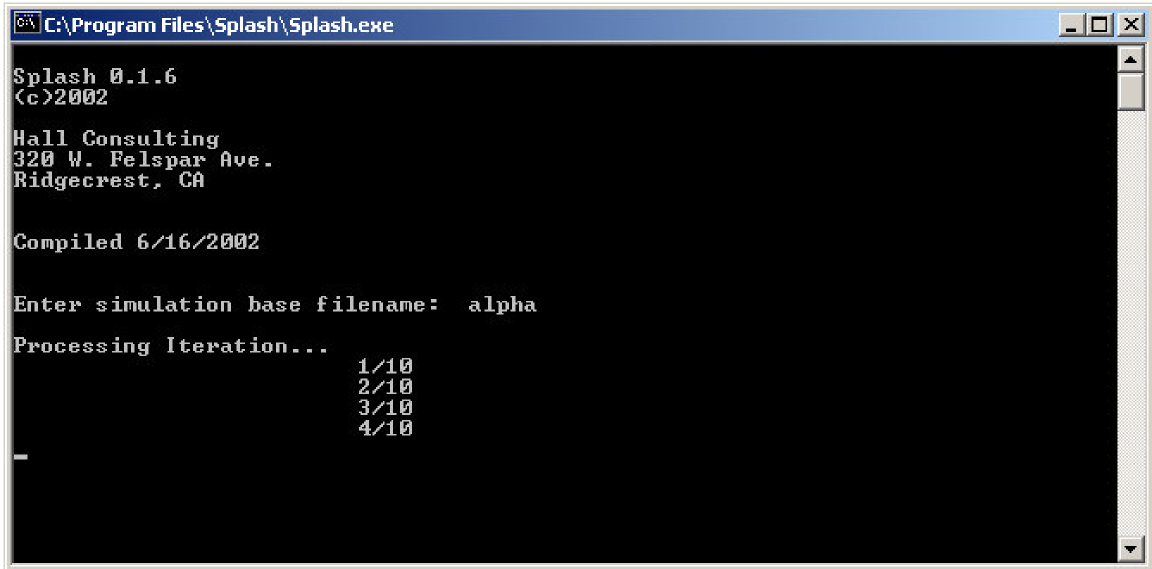
A screen capture of Splash prompting for the base filename.

Output

Upon execution, Splash produces a number of data streams. The first and most obvious is the screen output. In addition to screen output, Splash generates anywhere from two to five data files.

Screen Output

The Splash console application produces very limited screen output. In fact, this output is limited to nothing more than a progress update. As Splash begins each simulation iteration it echoes the current iteration number and the total iterations requested by the user. Nothing more. Nothing less.

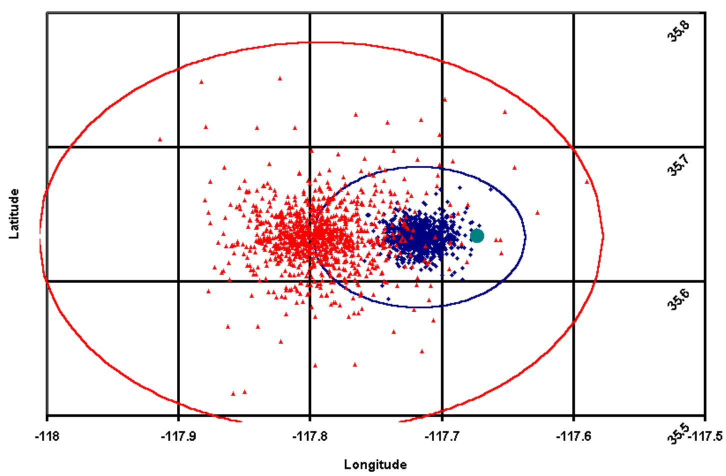


A screen capture of Splash as it processes the 12th of 10 iterations designated by the scenario "alpha".

Splash Pattern File

The splash pattern file is perhaps the most significant output file; it is what sets Splash apart from other 6DOF codes. More to the point, the splash pattern file contains a list of every impact point generated by every stage in every scenario simulated[20]. It is this data that ultimately determines the 3-sigma circle required of the FAA for a launch license.

As with all other input and output files used by Splash, there is a naming convention associated with splash pattern files. All splash pattern files are named by appending "_spl.out" to the base filename. For example, if the base filename is "alpha", then the corresponding splash pattern file will be named "alpha_spl.dat".



An Excel plot displaying splash pattern data for 1000 flights of a boosted dart. Blue diamonds denote impact point for the booster. Red triangles denote impact points for the dart. Similarly the blue oval represents a 3-sigma oval for the booster while the red circle

---

[20] Assuming the scenario file calls for multiple simulation iterations. If only one iteration is requested, then no splash pattern file is generated.

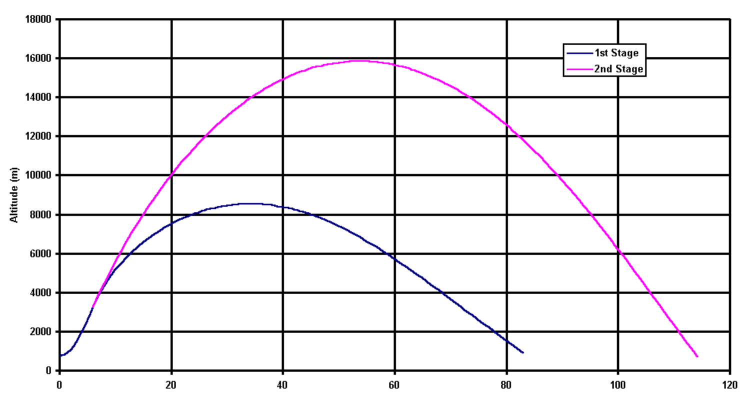
represents a 3-sigma oval for the dart. The green dot denotes the launch point.

Splash pattern files are simple text files containing simple columns of data. The format of these columns is as follows:

Column	Description
Run	The iteration or run number. While most runs include the randomization required of a Monte-Carlo analysis, it should be noted that the 0th run does not include any randomization. In other words, the 0th run is the nominal trajectory.
1Longitude	Longitude of the 1st stage impact point in degrees. A negative angle corresponds to West longitude.
1Latitude	Latitude of the 1st stage impact point in degrees. A negative angle corresponds to South latitude.
2Longitude	Longitude of the 2nd stage impact point in degrees. A negative angle corresponds to West longitude.
2Latitude	Latitude of the 2nd stage impact point in degrees. A negative angle corresponds to South latitude.
3Longitude	Longitude of the 3rd stage impact point in degrees. A negative angle corresponds to West longitude.
3Latitude	Latitude of the 3rd stage impact point in degrees. A negative angle corresponds to South latitude.

Trajectory Files

Splash generates anywhere from two to four trajectory files per execution. One file is generated to describe each stage's flight[21] and a final file compiles selected portions of the stage trajectory files to generate a single nominal trajectory.



An Excel plot generated with time/altitude data taken from two different Splash stage trajectory files illustrates the trajectory of each stage of a boosted dart.

The most informative of Splash trajectory files are the stage trajectory files. These files contain data concerning the flight of each individual stage from the moment it separates from the previous stage to the moment it impacts the Earth.

[21] Thus generating one, two, or three of these trajectories files as appropriate to the number of stages in the vehicle.

Stage trajectory files share a common naming convention. Specifically, "X.out" is appended to the base filename where X is the number of the stage in question. For example, if the base filename of the simulated scenario is "alpha", then the trajectory data for the first stage would be found in the file named "alpha1.out". Similarly, the trajectory data for the second and third stages would be found in the files "alpha2.out" and "alpha3.out" respectively.

The remaining trajectory file, the nominal trajectory file is the file that is most likely to be of initial interest to users. This trajectory file combines the most "interesting" data from the stage trajectory files to create a single trajectory. This trajectory describes the flight experienced by the vehicle if one assumes that boosters are no longer of interest after they separate from later stages.

The name of the nominal trajectory file is nothing more than ".out" appended to the scenario base filename. For example, if the base filename of the simulated scenario is "alpha", then the nominal trajectory file is named "alpha.out".

Beyond the fact that the various trajectory files describe trajectories associated with different objects, they are otherwise identical. All are text files. All share the same collimated data structure. The format of the data found in these files is as follows:

Column	**Description**
Time	Total time elapsed since beginning of simulation.
Longitude	Longitude (deg).
Latitude	Latitude (deg).
Altitude	Altitude (m, ASL).
Azmth	Body azimuth (deg).
Eleva	Body elevation (deg).
Roll	Body roll (deg).
AbsVel	Velocity with respect to the center of the Earth (m/s).
RelVel	Velocity with respect to a point on the surface of the Earth at the same longitude and latitude as the vehicle (m/s).
AirVel	Velocity with respect to the local air, i.e., air speed (m/s).
YawRt	Yaw rate (deg/s).
PitRt	Pitch rate (deg/s).
RolRt	Roll rate (deg/s).
Gamma	Flight angle (deg).
Headg	Heading (deg).
Mach	Mach number.
AOA	Angle of attack (deg).
Axial	Axial aerodynamic force (N).
Ca	Axial aerodynamic force coefficient normalized to the vehicle's nominal frontal area.
Normal	Normal aerodynamic force (N).
Cn	Normal aerodynamic force coefficient normalized to the vehicle's nominal frontal area.
Mass	Total vehicle mass (kg).
Mdot	Combined mass flow rate (kg/s) through all 5 motor nozzles.
Thrust1	Thrust (N) generated by motor 1.
Thrust2	Thrust (N) generated by motor 2.
Thrust3	Thrust (N) generated by motor 3.
Thrust4	Thrust (N) generated by motor 4.
Thrust5	Thrust (N) generated by motor 5.
Prop1	Propellant (kg) remaining in motor 1.
Prop2	Propellant (kg) remaining in motor 2.
Prop3	Propellant (kg) remaining in motor 3.
Prop4	Propellant (kg) remaining in motor 4.
Prop5	Propellant (kg) remaining in motor 5.

Appendices

Tips and Tricks

This portion of the manual is nothing more than a listing of tricks a user may employ to model vehicles or situations that may not be obviously supported by Splash.

Dual Deployment

Many high altitude vehicles employ a 2-stage recovery system. That is to say that they deploy a very small drogue chute at high altitude followed by the deployment of a large parachute at low altitude. While Splash does not directly support such systems, it can be tricked into modeling such systems provided that they are 2-stage or less vehicles. How?

1. Set up the input data files/windows normally.
2. Set the final stage' s recovery criterion such that the deployment occurs at the same moment that it is wished for the drogue chute on the dual deployment system to deploy. The recovery system properties for this stage should match those of the drogue chute.
3. Set the final stage' s staging criterion such that the stage separates at the same moment it is desired for the main chute on the dual deployment system to deploy.
4. Create a new "final stage". This stage does not exist in reality; it only exists in the model. This new stage should match the real final stage in every way shape and form, but it should deploy it' s recovery system *immediately*. The recovery system properties for this stage should match those of the main parachute.

The result of such a scenario will match that of a vehicle equipped with a dual deployment system. The only caveat is that some cutting and pasting will be in order to piece together the true trajectory from the trajectory data files.

Vacuum Total Impulse

Some users who attempt to program a pre-existing motor into Splash may find a small bit of confusion in the entry of total impulse. The performance parameters of many motors are listed under vacuum conditions. Splash requires parameters to be under sea level conditions. In the event one is unaware, a total impulse conversion between these two conditions is rather trivial.

SeaLevelImpulse = VacuumImpulse - NozzleExitArea * 101.3 kPa * BurnTime

…or if you prefer English units…

SeaLevelImpulse = VacuumImpulse - NozzleExitArea * 14.7 psi * BurnTime

Known Bugs

Excessive pitch oscillation during ballistic descent

Currently the only known bug in Splash concerns yaw/pitch damping during ballistic descent after the vehicle experiences extremely high angles of attack (approx. > 160 degrees). Rooted within the yaw/pitch damping algorithms, the bug results in a grossly underdamped yaw/pitch oscillation. This oscillation will eventually dampen out rather quickly once the amplitude of the oscillation falls to about 280 degrees. In addition, it does not appear that vehicles under parachute suffer from the bug. Fortunately, the extreme angles of attack that bring about this bug are rarely seen in _realistic_ scenarios.

New Features & Bug Fixes

Version 1.1.0

1. Support for English units was added to the GUI. Note that internally Splash still uses the SI system.
2. The propulsion input window in the GUI was totally revamped. The new window is less intimidating but just as easy to use.
3. A maximum flight time of 3600 seconds (1 hour) was inserted into the console application. This allows users to "go for orbit" without putting Splash into an infinite loop.
4. As the copy protection scheme was giving a few users problems that ranged from cosmetic or disastrous, this has been removed.
5. At users' request, the install routine now adds a shortcut to the Splash GUI to the desktop.

Version 1.0.1

1. The install routine now copies the User's Manual to the hard drive.
2. A small bug that could result in negative thrust under certain circumstances was fixed.

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5) Warranty. Splash includes no warranty in any way shape or form. The user understands that while Splash represents the very best efforts of HC, HC does not possess the resources to fully verify and debug software in a manner consistent with major corporations.

About the Author

At this point, there are those who would rightfully question the capabilities of your average Joe to write such software. With this question in mind, a brief resume of sorts is offered…

1993-1995	*University Computing Services* *University of Oklahoma* Provided technical support to students and faculty with an emphasis on debugging programs written in ANSI compliant C.
1994	*Awarded Bachelors of Science in Mechanical Engineering* *University of Oklahoma*
1995-2001	*Weapons Engineering and Analysis Branch* *Naval Air Warfare Center, Weapons Division* Authored and employed various 3 and 6 DOF codes to simulate military weapon systems ranging from shoulder-fired rockets to IRBMs for both design and range safety purposes.
2001-2002	*Ordnance Test Support Branch* *Naval Air Warfare Center, Weapons Division* Provide engineering support for ordnance testing activities. These activities include the static firing of solid rocket motors of up to 1.5 million pounds thrust.

While this hardly qualifies the author as the world's leading expert on rockets and 6 DOF codes, it is hoped that the reader will concur that he's been around the block enough times to do an adequate job.

The author aboard a gen-u-ine made in theUSSR SA-2 Guide Line.

Glossary

3-sigma circle	An imaginary circle (or oval) on the ground that encircles all potential impact points of a given vehicle to three standard deviations.
Axial force	The aerodynamic force acting along the longitudinal axis of a flight vehicle. At zero degrees angle of attack, axial force is equivalent to drag.
Azimuth	An arc of the horizon measured between a fixed point and the vertical circle passing through the center of an object. In astronomy and navigation azimuth is usually measured clockwise from the north point through 360 degrees of rotation.
Base drag	The component of a vehicle's total drag that is due to aerodynamic effects at the aft end of the vehicle.
Ca	The axial force coefficient
CATO	The catastrophic failure of a rocket motor usually characterized by the failure of the motor casing.
Cb	The base drag coefficient
Center of gravity	The location on a finite body through which the centroid of gravitational forces acting on that body passes.
Center of pressure	The location on a finite body through which the centroid of aerodynamic forces acting on that body passes.
Cn	The normal force coefficient
Drag	The component of the total aerodynamic force acting on an airplane or airfoil that acts opposite to the velocity vector of a vehicle.
Dynamic pressure	The pressure exerted on a vehicle's leading edges due to the pressure exerted by moving air. Usually denoted as "Q".
Elevation	The angle of a vehicle or launch rail's longitudinal axis with respect to horizontal. Often denoted as "theta".
Ignition failure	A propulsion system failure defined by an igniter's failure to ignite a motor's propellant grain in a manner consistent with sustained combustion of said grain.
Lift	The component of the total aerodynamic force acting on an airplane or airfoil that acts perpendicular to the velocity vector.
Moment of inertia	A mass property that measures how "resistant" an object is to torque. More precise definitions are somewhat complex and math intensive; the reader is recommended to search for such a definition online.
Normal force	The aerodynamic force acting perpendicular to the longitudinal axis of a flight vehicle. At zero degrees angle of attack, normal force is equivalent to lift.
Pitch	The portion of any angular offset of the vehicle's longitudinal (X) axis with respect to the velocity vector that is about the horizontal (Y) axis.
Product of inertia	Closely related to the moment of inertia, the product of inertia measures the dynamic balance of a rotating object. Again, precise definitions are complex and math intensive; again an online search is recommended for clarification.
Q	Dynamic pressure.
Roll	The angular position of a vehicle's dorsal fin or "top" with respect to horizontal.
Specific impulse	Defined as the instantaneous thrust divided by propellant burn rate, specific impulse proves a benchmark by which the efficiency of a propulsion system may be measured.
Splash pattern	A graphical representation illustrating numerous impact points of a given vehicle on which a Monte Carlo uncertainty analysis has been performed.
Total impulse	Defined as the integral of a motor's thrust/time curve, the total impulse provides a benchmark by which the "size" of a motor may be measured.
WGS-84	The Earth model used in the Global Positioning System (GPS).
Yaw	The portion of any angular offset of the vehicle's longitudinal (X) axis with respect to the velocity vector that is about the vertical (Z) axis.
Zipper	A recovery system failure mode in which the parachute (or other drag-inducing device) is physically separated from the rest of the vehicle.

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